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Redundancy gain in semantic categorisation☆

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ABSTRACT

Redundancy gain refers to the performance enhancements often associated with the presentation of redundant versus single targets (for example, faster, more accurate, or more forceful responses). Though predominantly observed in relatively simple tasks (e.g., stimulus detection), there have been some efforts to investigate similar phenomena in tasks involving higher level processing. We conducted three experiments aimed at determining (a) whether a redundancy gain would be evident in a task unambiguously requiring higher level processing (the semantic categorisation of visually-presented lexical stimuli), and (b) if so, what accounts might be appropriate to explain such findings. We found that redundancy gains are observed in such tasks, and we conclude that both coactivation and race models can account for these gains.

1. Introduction

In a phenomenon known as *redundancy gain*, performance is enhanced by the presentation of multiple stimuli prompting the same response (compared to when a single such stimulus is presented). This enhancement can take any number of forms, such as decreased response latency (Grice, Canham, & Boroughs, 1984; Hershenson, 1962; Miller, 1982, 1986; Todd, 1912), decreased error rate (Baird & Burton, 2008; Mohr, Landgrebe, & Schweinberger, 2002; Mohr, Pulvermüller, Mittelst dt, & Rayman, 1996; Mohr, Pulvermüller, & Zaidel, 1994, 2002), and more forceful responses (Giray & Ulrich, 1993; Mordkoff, Miller, & Roch, 1996). However, exactly what mechanisms lead to redundancy gain is a source of some debate (e.g., Miller, 1982; Mordkoff & Yantis, 1991; Raab, 1962; Townsend & Nozawa, 1997).

Redundancy gain has predominantly been demonstrated in lower level tasks such as simple sensory detection (e.g., Savazzi & Marzi, 2002; Schwarz & Ischebeck, 1994; Veldhuizen, Shepard, Wang, & Marks, 2010). Nonetheless, there have also been efforts to apply redundant target paradigms to the investigation of higher level processing. These have included the use of tasks such as fame judgements for faces (Baird & Burton, 2008; Mohr et al., 2002; Schweinberger, Baird, Blümler, Kaufmann, & Mohr, 2003), lexical decision (e.g., Mohr, Pulvermüller, Rayman et al., 1994; Mohr, Pulvermüller, & Zaidel, 1994; Mohr et al., 1996; Mullin & Egeth, 1989), emotion recognition (e.g., Collignon et al., 2008, 2010; Tamietto, Adenzato, Geminiani, & de Gelder, 2007; Tamietto, Latini Corazzini, de Gelder, & Geminiani, 2006), and object recognition (Molholm, Ritter, Javitt, & Foxe, 2004; Suied, Bonneel, & Viaud-Delmon, 2009). In each of these cases, redundancy gains have been observed. This seems to indicate that redundancy gain is not limited to simple experimental tasks, but could instead be a more general principle of human information processing.

However, whether tasks purporting to demonstrate redundancy gain in higher level processing have actually done so may be questioned. For instance, studies investigating object and emotion recognition, undertaken by Molholm et al. (2004), Collignon et al. (2008, 2010), and Suied et al. (2009), involved small sets of stimuli that were presented repeatedly. This could have allowed participants to build low level S–R associations, which in turn could have obviated the need for any higher level processing in completing the tasks. Thus, the redundancy gain might just have emerged within the processing of low level S–R associations. This was also the case for lexical decision and semantic categorisation experiments undertaken by Mullin and Egeth (1989). Other studies have also involved confounds between redundancy at higher and lower levels of processing. For example, Tamietto et al.'s (Tamietto et al., 2006, 2007) studies of the recognition of emotional facial expressions unavoidably

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involved perceptual as well as emotional redundancy, since facial expressions are defined by their physical features. As perceptual redundancy has been demonstrated to lead to gains even with visually complex stimuli (e.g., faces; Jiang, Kwon, Shim, & Won, 2010), the effects of redundancy on emotion recognition could have been mediated by the processing of physical features rather than higher level emotional concepts.

The results of Mohr and Pulvermüller (e.g., Mohr, Pulvermüller, Rayman et al., 1994; Mohr, Pulvermüller, & Zaidel, 1994; Mohr et al., 1996) using lexical decision tasks (LDTs) appear to provide somewhat stronger evidence of redundancy gain in higher level processing. In these experiments, participants were presented with one or two copies of a word or non-word on each trial, and asked to make manual "word" or "non-word" responses. Findings showed faster and more accurate responding in redundant than single-target trials, but only for words (there were limited or no effects of redundancy on non-words). While individual stimuli were repeated rarely or never, redundant trials involved not only lexical redundancy, but also perceptual redundancy (as multiple copies of the same word or non-word were presented simultaneously). However, had perceptual redundancy been the source of the gains there is no obvious reason they should not have occurred for non-word stimuli as well. Thus, the overall pattern of results provides some support for the idea of redundancy gain in higher level (i.e., word recognition) processes.

Mohr et al. (Mohr, Pulvermüller, Rayman et al., 1994; Mohr, Pulvermüller, & Zaidel, 1994; Mohr et al., 1996) explained their results with reference to a neurobiological model of language, based on the concept of Hebbian cell assemblies (e.g., Hebb, 1949). According to this model, words are represented in the brain as collections of cells spread throughout the cortex—that is, cell assemblies. When a word is presented, its cell assembly is activated, leading participants to make a "word" response. When two copies of a word are presented, this provides extra activation to its cell assembly, and the response can be made more rapidly. By contrast, unfamiliar non-words do not possess such representations, and thus are unable to benefit from redundant stimulation.

The cell assembly model offers an account of how redundancy gain might occur in a task involving higher level processing (in this case, judgements about "wordness"). Under the theory that similar findings should be evident not just for words but for all complex stimuli possessing existing neural representations, further studies showed redundancy gains in a fame judgement task. In this task photographs of faces were presented singly or redundantly and participants were asked to judge whether or not they belonged to "famous" people (e.g., Baird & Burton, 2008; Mohr et al., 2002; Schweinberger et al., 2003). Analogously to the findings in lexical decision, these gains occurred for "famous" faces, but not "non-famous" faces. Mohr et al. (2002) suggested that this was due to only famous faces being familiar and thus having neural representations whose activation could be enhanced by dual stimulation.

However, despite circumventing some of the problems with other experiments showing redundancy gain in tasks which may have involved higher level processing, results from lexical decision and fame judgement tasks also fail to provide unequivocal evidence of a higher level redundancy gain. Though decisions about lexicality and fame can certainly make use of complex information (see, e.g., Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; James, 1975), they also have the potential to be made entirely on the basis of stimulus familiarity (e.g., Balota & Chumbley, 1984). Whether a judgement of familiarity could really be said to require higher level processing is debatable, meaning that the existence of redundancy gain in higher level processing is still an open question.

In addition to uncertainties about the level of processing underlying redundancy gains found in the lexical decision and fame judgement tasks, the mechanism behind the gains is also open to debate. Generally, accounts of redundancy gain take one of two forms: coactivation models, and race models. In coactivation models, evidence from redundant stimuli is somehow summed, facilitating responses. As such, the cell assembly model falls under this umbrella. Race models, by contrast, suggest that redundant stimuli are processed in parallel but separately, and that gains result from the statistical facilitation caused by both stimuli "racing" to activate a response. One frequently-used method of determining which explanation is appropriate in a redundant target experiment is through the use of Miller's (1982) race model inequality (RMI). This inequality describes the limit to the possible extent of reaction time enhancement through statistical facilitation. This limit can be modelled using RT data from single-target trials, and if RTs in redundant trials are faster than the modelled RTs—that is, if the RMI is violated—then a race model explanation can be ruled out. Unfortunately, coactivation models do not necessarily produce violations of the RMI, so failures to observe such violations are not strong support for race models.

Mohr et al.'s (1996) preference for the cell assembly model was based largely on its biological plausibility. Though they provided other evidence from their results to rule out an alternative race model-based explanation, they only rejected a very specific race model in which the two cerebral hemispheres each processed separate stimuli. There are other race models which fit equally as well with the data from LDTs and fame judgement tasks as does the cell assembly coactivation model. For instance, the finding that redundancy gain occurred only for positive (word/"famous") stimuli and not for their negative counterparts (non-word/"non-famous")—used to support Mohr et al.'s argument for the cell assembly coactivation account—could simply be a result of a self-terminating race. In this account, positive responses can be directly elicited by stimuli (and thus benefit from the statistical facilitation associated with redundant targets) but negative responses require a temporal threshold of some sort to be reached (and thus are unable to receive the same benefit irrespective of the number of nontarget stimuli presented). As the RMI was not tested in any of the studies mentioned (e.g., Baird & Burton, 2008; Mohr, Pulvermüller, & Zaidel, 1994, Mohr et al., 1996; Schweinberger et al., 2003), such an alternative model cannot be ruled out.

Stronger evidence for redundancy gain in higher level processing comes from a recent study by Fiedler, Schr ter, and Ulrich (2013), who demonstrated redundancy gain in the processing of categorical and physical features associated with the objects denoted by visually presented words. In Fiedler et al.'s experiment, participants completed a go/no-go task where they were asked to respond if a word described an entity either belonging to a specified superordinate category (animals), an entity possessing a certain physical feature (grey in colour), or both. Fiedler et al. found a significant redundancy gain for words designating objects matching both target criteria (e.g., "elephant"), but no RMI violations. They concluded that the redundancy gain could be explained by a race model (i.e., statistical facilitation) in which the processes analysing the categorical and physical features of the indicated object operate in parallel, with the first one to finish activating the response. Thus, this study shows that information about an object's abstract semantic properties (i.e., category) can participate in redundancy gain with information about a more concrete, physical property (i.e., colour) when both are retrieved from memory.

Given that Fiedler et al.'s (2013) findings provide strong support for redundancy gain during higher level processing of the semantic representation denoted by a single word (e.g., "elephant"), it seems logical to ask further whether redundancy gain can also arise during the processing of two words with different lexical entries. The present experiments were designed to answer this question within a task where there was a single target attribute defined by semantic category, and the redundant items consisted of different words within that category. In addition, as in Fiedler et al.'s study, we sought to determine whether any observed redundancy gain could best be explained by parallel or serial self-terminating models.

2. Experiment 1

This experiment used a semantic categorisation task with lexical stimuli, based on the LDT studies of Mohr and Pulvermüller (e.g., Mohr,