

Species of Redundancy in Visual Target Detection

Boaz M. Ben-David
University of Toronto

Daniel Algom
Tel-Aviv University

We report a series of investigations into the effects of common names, physical identity, and physical similarity on visual detection time. The effect of these factors on the capacity of the system processing the signals was also examined. We used a redundant targets design with separate testing of the target-distractor (single target), target-target (redundant targets), and distractor-distractor (no targets) displays. When a target and a distractor share names, detection of the target is slower than it is in a situation in which the two do not go by a common name. Nevertheless, the gain reaped by redundant targets in this situation is larger and signal processing is of increased capacity compared with those in a situation in which the target and the distractor are coded by different names. The results also highlight the role of physical identity of targets: Detection is disproportionately efficient when reproductions of a given signal are presented. Together, the results provide guiding principles for a model of visual detection by a context-sensitive human detector.

Keywords: common names, similarity, redundant signals, capacity, letters

Virtually every behavioral act is prompted by multiple signals. Reaching for the brakes in your car can be engendered by the red lights in the intersection, by the police officer signaling to stop, or by a little girl crossing the road. When more than a single signal is present, they are redundant because each signal alone is sufficient for triggering your braking response. Nevertheless, the presence of multiple signals can improve performance (the red lights and the officer likely produce a faster braking response than does either signal alone), the Redundant Targets Effect (RTE). The context includes, of course, other stimuli unrelated to your braking response (e.g., placards, buildings), which should be momentarily ignored. This routine situation of everyday life is captured in the laboratory via the well-known Redundant Targets Design (RTD). Of the set of stimuli, some are defined as targets, and the others as distractors. A pair of stimuli is presented on each trial, and observers respond “Yes” when the display contains *at least* one target, otherwise they responds “No.” Consequently, a trial in the RTD can include two targets (redundant-targets displays), a target and a distractor (single-target displays), or two distractors (no-target displays). There is a voluminous literature on various aspects of the RTD, in particular on the phenomenon of the RTE

(e.g., Miller, 1982, 1991; Schwarz, 1989; Townsend & Nozawa, 1995; Townsend & Wenger, 2004; see also Miniussi, Girelly, & Marzi, 1998, for a possible neural site for the RTE). However, a notable exception is the paucity of RTD research on the similarity relations among the pertinent stimuli; there are few studies, which acknowledge a role for stimulus identity, similarity, or common name and semantic codes. The goal of the present study was to test the effect of physical identity, physical similarity, common name codes, and common meaning on performance in all facets of the RTD (target-target, target-distractor, and distractor-distractor displays, the RTE, and capacity).

The Effect of Physical Similarity: Target-Target, Target-Distractor, and Distractor-Distractor Displays

Presenting a target that bears physical semblance to the distractor can affect detection differently than presenting pairs of similar targets or pairs of similar distractors. Shared physical features between a signal and a distractor can act as a camouflage of sorts to impede detection of the signal (e.g., Bjork & Murray, 1977; see also, Duncan & Humphreys, 1989, 1992, on the disadvantageous effect of distractors-target similarity in visual search). Given the slower detection of the target when it bears physical similarity to the distractor, the RTE is expected to be larger (consult Townsend & Nozawa, 1997, on the relativity of the RTE and the caution that should be exercised in its interpretation). For displays entailing a pair of targets only, physical similarity between the targets is not expected to confer an advantage in detection compared with pairs of dissimilar targets. In fact, the latter might be detected faster (a “different-targets-advantage,” Grice & Reed, 1992; Mordkoff & Miller, 1993) because of the larger semantic network associated with distinct targets. For distractor-distractor displays, similarity between the distractors is not expected to impact the decision about the absence of a target in a significant fashion. This minimum effect on rejection is a mirror image of that engendered by target-target similarity on detection (cf. Egeth & Dagenbach, 1991). All of these predictions were tested in the present study.

Boaz M. Ben-David, University of Toronto; Daniel Algom, Tel-Aviv University.

Portions of this research are based on a doctoral dissertation completed at Tel-Aviv University by Boaz M. Ben-David under the supervision of Daniel Algom. During the preparation of this article, the first author was partially supported by a strategic training grant (Communication and Social Interaction in Healthy Aging), and a group grant on Sensory and Cognitive Aging, both funded by the Canadian Institutes of Health Research. The second author was partially supported by an Israel Science Foundation grant (ISF221-0607).

Correspondence regarding this article should be addressed to Boaz M. Ben-David, the Centre for Research on Biological Communication Systems, University of Toronto, Mississauga, 3359 North Mississauga Road, Mississauga, Ontario, Canada L5L 1C6. E-mail: boaz.ben.david@utoronto.ca

We presented pairs of letters as stimuli in our study. Similarity referred to their physical appearance defined by case (*AN* similar, *An* dissimilar). We also tested the effect of identity or sameness (in the extreme, similarity is sameness; cf. Farrel, 1985) not just for visual shape, but also for names and meaning. A pair of letters can be same in (at least) three ways: by physical identity (*AA*), by shared names (*Aa*, nominal identity), or by shared meaning (*Ae* entails vowels, semantic identity). Each of these species of sameness can affect performance in a different manner.

Species of Sameness: Physical Reproductions, Common Name and Semantic Codes

Physical Identity

We predicted that presenting physical reproductions (whether of targets or of distractors; a target and a distractor cannot be the same or detection is impossible) improves performance to a disproportionate degree. The reasons are threefold. First, physically identical signals always go by the same name and always mean the same thing, whereas nominally or semantically identical signals are not necessarily so congruent. Thus, one expects that physically identical targets are detected (or are judged to be same) very speedily because of the (trivial) fact that such targets are congruent at all conceivable levels of analysis (Eviatar, Zaidel, & Wickens, 1994; Garner, 1988).

The paramountcy of physical sameness is also evident from a hierarchical “level-of-processing” perspective (Craik & Lockhart, 1972; see also Craik, 2002). Posner (Posner, 1978; Posner, Boies, Eichelman, & Taylor, 1969; Posner & Mitchell, 1967) found that participants classified pairs of letters as “same” on the basis of physical identity (*AA*) faster than they did on the basis of nominal identity (*Aa*). It took participants even longer to classify letters as “same” based on semantic category membership (e.g., *Ae* entails vowels). According to Posner and Snyder (1975), the observer first analyses the physical features of the stimulus. In an optional nominal level, the stimulus is labeled or identified by an alphanumeric code. Finally, at the semantic level of analysis the meaning of the stimulus is extracted. Because the nominal stage follows the physical stage, it takes longer to detect or classify nominally same targets than physically same targets. Because the semantic stage comes last, it takes even longer to detect or classify targets that are only semantically the same.

A third perspective that predicts an advantage of physically same targets is based on purely perceptual considerations. Duplicating a signal (e.g., *AA*) forms a better Gestalt than presenting physically different signals (cf. Pomerantz, Sager, & Stoeber, 1977). The configural properties of physically identical targets confer advantage on detecting or classifying such stimuli. In summary, three different perspectives converge on the conclusion that physical sameness enjoys a primary status in determining performance in visual detection and classification.

Common Name Codes

Consider now the effect of name. When the target and the distractor go by the same name, detection is impeded. This prediction is based on the diminished discriminability of the target and the distractor wrought by the common name. A shared name

renders the target less salient and hence more difficult to notice. This effect of name sharing emulates that of physical similarity: Both contexts act to camouflage the target (Bjork & Murray, 1977). The effect of name sharing reaches even to memory. When the display contains only targets, the presence of a distractor with the same name in the overall stimulus ensemble can still hamper detection. Detection is determined not only by the presented stimuli, but also by those stimuli that could have been presented although were not presented in a particular instance. We espouse this fundamental tenet of information theory (Garner, 1962, 1974) and predict that it plays a role in visual detection as well.

Thus, a common name code is a factor to reckon with in mixed (target-distractor) displays (on a par with physical similarity), but it plays a lesser role with single-class displays. With the latter displays, the supremacy of physical identity renders physical similarity and name sharing between targets or between distractors ineffectual.

Common Meaning

The effect of a common semantic code has not been subjected to systematic scrutiny within the RTD literature (indeed within the literature on additional tasks of visual detection). There is some evidence that targets with a common meaning (but that are different in all other respects) might enjoy an advantage in detection over redundant targets with a common name code or even over physically identical redundant targets (Grice & Reed, 1992). Given the scant available data (Posner, 1978; the situation has not changed substantially since Posner’s observations), we predict that a common semantic code does not materially effect rejection of distractor-only displays, but has a slight detrimental effect on detection in target-distractor displays.

In the remainder of the introduction, we discuss three important issues associated with the quest at unraveling the sundry effects of sameness, similarity, and common name and semantic codes on visual target detection.

The Nature of the RTE

A hallmark of performance in the RTD is the gain in detection reaped by the presence of double (or multiple) targets: Reaction times are stochastically faster on double- or redundant-targets trials than on single-target trials (e.g., Townsend & Nozawa, 1995; Townsend & Honey, 2007; Westendorf & Blake, 1988). The magnitude of the RTE, in turn, reflects on the nature of processing. If the two targets present are processed in parallel (i.e., one channel does not have to wait for the other to finish before it can start processing its own input), then a simple routine can help to decide whether there is an interaction between the targets in processing. The race model inequality (Miller, 1982) states that the probability of a fast detection response to redundant targets cannot exceed the sum of the probabilities for similarly fast detection responses to each of the individual targets alone—if the individual targets (in the redundant display) are processed separately. Violation of the inequality is interpreted as evidence showing that the two targets interact in processing. The observed speedup on trials with redundant targets (RTE) is naturally produced by such an interaction. Alternatively, with the inequality satisfied, the RTE may merely tap statistical facilitation with separate channels (e.g., Raab, 1962).

A recent theoretically precise approach to capacity (Townsend & Nozawa, 1995; Townsend & Wenger, 2004) shows that satisfying the race model inequality is tantamount to a system operating with limited or unlimited capacity, whereas violation of the inequality implies supercapacity. Unlimited capacity means that a target is processed in an invariant fashion regardless of the activity in the other channels (i.e., regardless of the presence of redundant targets). Limited capacity means that efficiency with a given target is impaired as the number of active channels (targets) increases. Supercapacity means that processing of a target is more efficient as the number of active channels increases. We tested the race model inequality and the new measures of capacity in our study. In particular, we wished to examine the effect of shared names between target and distractor on the RTE and on the capacity with which the target stimuli are processed. We return to discuss and elucidate these measures in a rigorous fashion in Experiment 1.

Species of Sameness and the RTE

In the majority of laboratory studies (Table 1), redundant targets were created by the physical duplication of a signal. It is not always recognized that even with physical replicas the RTE can result from *different* sources. It can result from the physical sameness of the two signals (the default or tacit assumption in portions of the literature), but it can also result from the common name of the two signals or from the common meaning of the two signals (different-targets advantage?). Consequently, a given RTE with physical replicas—the common practice in the literature—can be produced by any one of the three species of sameness or by any combination of them. The basic question is this. To what extent can the target stimuli differ physically yet still be redundant?

Grice and Reed (1992) considered the effect of shared names over and above that of physical identity of targets within the RTD (see also Egeth and Santee, 1981). Surprisingly, detection was faster for different targets (*AD*) than for identical targets (*AA*, *DD*). The authors concluded that, “stimulus redundancy is primarily an associative rather than a perceptual process. Stimuli are redundant if they lead to the same response” (p. 441). Grice and Reed’s (1992) conclusion is consistent with grounding the RTE in semantic identity: Signals are redundant if they mean the same thing (which may merely comprise experimental directions for responding). Mordkoff and Miller (1993) replicated the Grice and Reed study, controlling for target preferences and inter-stimulus contingencies, and found performance on different-targets trials to be at least as good as (but not better than) performance on identical targets trials. In this study, we addressed in a systematic fashion the effect of physical, nominal, and semantic kinship among signals on their detectability.

Letter Name and Abstract Letter Identity (ALI)

Coltheart (1981) lists three criteria by which a pair of letters, indeed a pair of stimuli of any kind, can be judged to be “same”: by semantic code (when the two stimuli have the same meaning), by phonological code (when the two stimuli have the same pronunciation), or by visual code (when the two stimuli are visually identical). Subsequent research (Besner, Coltheart, & Davelaar, 1984; Brundson, Coltheart, & Lyndsey, 2006; Coltheart, 1981; Coltheart & Coltheart, 1997; Evett & Humphreys, 1981) has

shown that the list of codes is not exhaustive because letter processing can be preserved when each is eliminated. An abstract code, conceived to be neither visual nor phonological, is activated at an early stage to compute letter identity. The ALI code is actually identical to the alphanumeric code suggested by Posner within the “level-of-processing” scheme recounted earlier (a tentative argument by Besner et al., 1984, that equates Posner’s alphanumeric code with a phonological code is not tenable). The function of names is to identify the referent stimuli – independent of incidental variations in appearance (in visual shape, pronunciation, order, and further phonemic and graphemic characteristics). This effect of (shared) names was tested in our study.¹

The research on ALI also shows that nominally identical different-case letters (*Aa*) belong to the same abstract category and hence are differentiated based on physical appearance. Following ALI, different letters in a pair are always coded in a distinct manner regardless of case or similarity in pronunciation. However, a semantic criterion for classification can be introduced over and above the initial ALI (e.g., “vowel-ness,” Posner, 1978). We also tested the effect of such semantic relatedness on detection in our study.

Overview of the Experiments

The first two experiments focused on target-distractor relationship. In Experiment 1, we examined the effect of name sharing between the target and the distractor on target detection. In Experiment 2, we further examined the effect of physical similarity between the target and the distractor on detection. The focus shifted in the next three experiments to the composition of the targets and that of the distractors. In Experiment 3, we tested the effect on detection of name sharing between the targets (and between the distractors). In Experiment 4, we tested the effect on detection (and rejection) of physical similarity between targets (and between distractors). Finally, in Experiment 5 we tested the effect of (a) physical sameness, (b) physical similarity, (c) nominal sameness, and (d) semantic sameness of targets and of distractors in a powerful within-participant design. In addition to the respective summary statistics, we also derived the RTE, the race model inequality, and the Townsend measures of capacity in all of the experiments.

¹ The quite voluminous research on ALI and related phenomena has been completed within the study of reading processes. Our interest in this research is different. We sought to isolate and characterize the effects of various species of similarity and sameness on visual detection. We elected to present letters as stimuli for two reasons: (a) letters lend themselves easily to form various levels of sameness and similarity, and (b) the great bulk of RTD research used letters as stimuli (see Table 1 again). Considering the present interests, three further points should be appreciated. First, the response was speeded detection, not reading aloud or comparison of words as in ALI research. Second, the pairs of letters appeared aligned vertically with spatial separation, which further reduced involvement of reading except for stimulus identification and detection. Finally, with single letters one cannot distinguish ALI from phonological code (hence, the use of words or nonwords in ALI studies of reading). Because this study focused on the effect of names, this distinction is inconsequential.

Table 1
Classification of Letters Into Targets and Distractors in a Sample of Visual Search Experiments With Redundant Targets

Study	Target(s)	Distractor(s)
Mordkoff and Yantis (1991)	X	O, I
Egeth and Dagenbach (1991)		
Exp. 1	X	O*
Exp. 2-3	T, rotated T	L, or Rotated L
Mordkoff and Egeth (1993)	X	O, I
Townsend and Wenger (1999)	X	O
Wenger and Townsend (2000)	X	O
Mordkoff, Yantis, and Egeth (1990)		
Exp. 1-2	X in red	O in red, X in green
Exp. 3	X in red	O, I, X in red, green, blue
Miller and Reynolds (2003)	X, I in green	I, O in cyan or magenta
Miller (1982)		
Exp. 3	X	O
Exp. 4-5	A	H, I, M, O, T, U, V, W, X
Miller (1991)	X, H	K*
Grice, Canham, and Boroughs (1984)	H	S* Y (Navon figures)
Grice, Canham, and Gwynne (1984)	H	S*, and Y
Grice and Canham (1990)	H	S*, and Y
Grice and Gwynne (1987)	H	S*, and Y
Eriksen and Eriksen (1979)	H, S	K, C*, and N, W, Z or G, J, Q
Theeuwes (1994)	E	F
Van der Heijden (1975)	E	F
Van der Heijden, Schreuder, Maris, and Neerincx (1984)	E	O
Van der Heijden and La Heij (1982)	E	O or F
Van der Heijden and La Heij (1983)	E	O or F
Van der Heijden, La Heij, and Boer (1983)	E	O or F
Eriksen, Goettl, St. James, and Fournier (1989)		
Exp. 1	S	C*, and H, Z, K, N, V, W
Exp. 2	A	Y* and H, V
Fournier and Eriksen (1990)		
Exp. 1	A, N	H, K* and M, W or S, C
Exp. 2	X	O*
Santee and Egeth (1982)		
Exp. 1	A, R, T	B, E, Z
Exp. 2-4	A, E	K, L
Santee and Egeth (1980)		
Exp. 1,3,4	A, E	K, L
Exp. 2	B, R	P
Egeth and Santee (1981)		
Exp. 1,3	A, E	a, e and K, L
Exp. 2	N, R	n, r and D, U
Eriksen, Morris, Yeh, O'Hara, and Durst (1981)	A, E	K, L
Grice and Reed (1992)		
Exp. 1	A, a	E, e* and Y, y
Exp. 2	A, D	E, R* and Y
Bjork and Murray (1977)	B	R*, and P, K
Mordkoff and Miller (1993)	B, D	All other consonants*

* These targets and distractors were used interchangeably. There were 46 experiments (Exp.) collected from 29 published studies.

Experiment 1: Shared Names of Targets and Distractors

The goal of Experiment 1 was to examine the effect of name sharing between targets and distractors upon detection of the targets. To this end, the letters *A* and *D* (as target and distractor) were presented in one condition, and the letters *A* and *a* in another condition. The former stimuli are different physically and nominally (as well as semantically), a common characteristic of redundant targets studies. The latter stimuli are also different physically, but are the same nominally and semantically. Does name sharing make a difference? We predicted that it does, impacting detection

in a negative fashion and affecting perhaps other features of performance.

Method

Participants

Thirty-six Tel-Aviv University undergraduates participated in partial fulfillment of course requirement. All participants in this and the subsequent experiments had normal or corrected-to-normal visual acuity assessed by self-report; their age ranged between 20

and 35 years. There was an equal number of men and women selected, a routine that we (approximately) followed in all subsequent experiments. A random half of the participants performed in a condition with the letters *A* and *D* as the stimuli, whereas the other half performed in the condition with the letters *A* and *a* as the stimuli.

Stimuli, Apparatus, and Design

The method was largely (though by no means fully) tailored after that by Grice and Reed (1992). In one condition with 18 of the participants, the stimulus set comprised the capital letters *A* and *D*. On a trial, two letters appeared one placed above the other at the center of the screen. The stimuli (Arial, bold, size 24) were generated by a Macintosh G3 300 computer and displayed black on the gray background of a 17-in flat color monitor (100 Hz refresh rate, set at a resolution of 1,024 × 768 pixels). The participants were seated at a viewing distance of approximately 60 cm from the center of the screen, such that each letter subtended 0.25° × 0.55° of visual angle. There was a trial-to-trial spatial uncertainty of up to 10 pixels around the center fixation point, but the letters were always aligned vertically one above the other.

For a random half of the participants, *A* was designated as the target and *D* as the distractor, and for the other half *D* was the target and *A* the distractor. The participants were instructed to press one key ("Yes") if at least one of the letters in the display was the target and another key ("No") if none of the letters presented was a target. Trials were response terminated. Responses were produced by pressing one of two keys on a standard keyboard ("A" to the left or ";" to the right) with the index finger of the appropriate hand (color patches covered these keys). The computer program registered response times and errors. Key assignment was nearly fully counterbalanced across participants.

There were 108 trials. The four possible displays: *AA*, *AD*, *DA*, and *DD* appeared 27 times each. They were preceded by 10 practice trials (unbeknownst to the participant).

In the other condition with the 18 remaining participants, the same methods were used with a single notable exception: The letter *a* replaced the letter *D*, such that the letters *A* and *a* now served as the target and the distractor (interchangeably). In this condition, the stimulus set comprised the upper- and lower-case forms of the letter *A* (presented in uniform visual size). The four possible displays thus were, *AA*, *aA*, *Aa*, and *aa*. For a random half of the participants in this condition, *A* was designated as the target and *a* as the distractor, whereas for the other half, *a* was the target and *A* the distractor.

Procedure

The participants were tested individually in a dimly lit room. The participants were encouraged to respond quickly but accurately. The instructions included three demonstration trials during which the participant was given accuracy feedback on each trial. After a short interval, the instructions were re-read and the experimental block began. Each trial began with the presentation of a fixation cross at the center of the screen for 500 ms. After a 100-ms blank interval, the stimuli appeared. As soon as a response was made, the stimuli were removed, and after an intertrial interval of

500 ms the next trial began. The experimental session lasted 10 to 15 min.

Results

The Condition With A and D as Target and Distractor

Error rates did not exceed 2% in all displays (and did not exceed 4% for any of the individual participants) and are not discussed further. The analyses of reaction time (RT) are restricted to correct responses in this and all subsequent experiments. Responses slower than 1,100 ms and speedier than 200 ms were discarded (less than 0.5% of the data). Performance was comparable across target letters (*A*, *D*) and target location (upper, lower). Neither target letter nor key assignment interacted with trial type ($F < 1$, for all three terms). Note also that the following analyses (as well as parallel analyses in subsequent experiments) are based on data pooled over the individual observers.

The RTE and the Race Model Inequality

The mean RTs for redundant- and single-target displays were 433 and 445 ms, respectively, yielding an RTE of 12 ms ($t(17) = 2.18$, $p < .05$, $\eta^2 = 0.219$). The slowest responses (499 ms, on average) were recorded with the no-target displays ($F(2, 51) = 4.40$, $MSE = 5,091$, $p = .02$, $\eta^2 = 0.147$).

How can one explain the phenomenon of the RTE? Assuming parallel processing of the two targets, it is natural to posit some kind of an interaction between the two processing channels to produce the observed speedup. However, facilitation when both targets are present can occur via statistical considerations alone (Raab, 1962; Townsend & Honey, 2007). In that case, there is a race between parallel channels, and the response on each particular (double-target) trial is determined entirely by the channel that wins the race. To decide between the alternatives, Miller (1982) pointed out that all race models must satisfy the inequality,

$$F_{U,L}(t) \leq F_U(t) + F_L(t),$$

where $F_{U,L}$, F_U , and F_L are the cumulative probability density or distribution functions for double- and single-target trials, respectively (the subscripts U and L refer, respectively, to upper and lower position of the target). The inequality means that the distribution function for trials in which both targets are present cannot exceed the sum of the distribution functions for trials entailing a single target—if indeed there is a parallel race at the basis of the RTE. Alternatively, violation of the race model inequality falsifies all race models, and implies that an interaction or coactivation of the two channels produces the RTE.

The pertinent results are presented in Figure 1. The distribution function for the double-target trials does not cross the sum of the distribution functions for the single-target trials. The race model inequality is not violated. Therefore, supercapacity or interaction is not supported. The present RTE likely resulted from the statistical advantage accrued by the presence of two targets with each processed separately.

The Grice Bound

There is a bound on limited capacity (as opposed to the race model bound on supercapacity) sometimes known as the *Grice bound* (Grice, Canham, & Gwynne, 1984). If the inequality

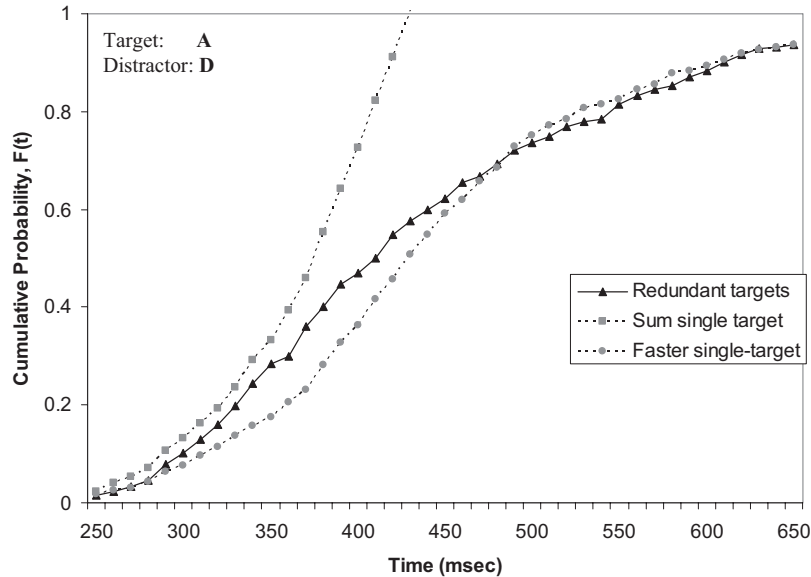


Figure 1. Tests of the race model inequality and the Grice bound in the condition with A and D as target and distractor (Experiment 1). The sum of the distribution functions for single targets does not cross the distribution function for double targets. Therefore, the race model inequality was not violated. The distribution function for the faster single target crosses the distribution function for double targets at around $t = 500$ ms. The Grice bound is violated in that region, indicating very limited capacity.

$$\text{MAX}[F_U(t), F_L(t)] \leq F_{U,L}(t),$$

is violated, then the system is limited capacity to a rather strong degree. In this case, performance on double-target trials ($F_{U,L}(t)$) is worse than that on single-target trials containing the faster of the two targets, $\text{MAX}(F_U(t), F_L(t))$.²

The results concerning the Grice bound are also shown in Figure 1. The distribution function for the faster single target crosses that for redundant targets at around 500 ms, implying limitations on capacity more severe than those imposed by the Grice bound (at those times t).

In summary, the results with respect to the Miller and Grice bounds suggest that the system is definitely not supercapacity. Moreover, the violations of the Grice bound suggest regions of very limited capacity. These conclusions are reinforced by the main test of capacity discussed next.

The Capacity Coefficient

It is now generally recognized that the race model inequality depends on the critical assumption of context invariance (Ashby & Townsend, 1986; Colonius, 1990; Luce, 1986), a constraint that affects its interpretation. The race model inequality is best considered (jointly with other measures) as a test reflecting on the capacity of the system (rather than on architecture). The association with capacity has been fully explicated for the measure known as capacity coefficient, $C(t)$ (Townsend & Nozawa, 1995).

Townsend and Nozawa (1995) defined a measure of capacity, $C(t)$, that gauges the extent to which target processing in one channel is impaired ($C(t) < 1$, limited capacity), left unaffected ($C(t) = 1$, unlimited capacity), or improved ($C(t) > 1$, superca-

capacity) by adding a target in the other channel. Formally, the capacity coefficient $C(t)$, is defined as

$$C(t) = \frac{H_{U,L}(t)}{H_U(t) + H_L(t)} \quad t > 0$$

² At those values of t where this occurs, the bound can be close to the level of *fixed capacity* defined by $H_{U,L}(t) = 1/2[H_U(t) + H_L(t)]$, where $H_U(t)$, $H_L(t)$, and $H_{U,L}(t)$ are the integrated hazard functions calculated for the single- and double-target trials, respectively. The integrated hazard function is defined as $H(t) = \int_0^t h(t) dt = \int_0^t \frac{f(t)}{S(t)} dt$ where $f(t)$ is the probability density at time t and $S(t)$ is the survivor function. The survivor function is the complement of the distribution function, $F(t)$, such that $S(t) = 1 - F(t)$. The hazard function, $h(t)$, thus is proportional to the probability that the processing of an item finishes at the next instant of time given that it has not yet been completed. If one interprets the hazard function in terms of the physical concept of power, then $H(t)$, the integral of the hazard function, can be interpreted in terms of the physical concept of energy or work. Therefore, calculating $H(t)$ provides for a natural way to measure capacity.

When the upper- and lower-position integrated hazard functions are identical (i.e., the two channels function at equal speed), the Grice bound becomes equivalent to fixed capacity; otherwise, it is a bit greater. Fixed capacity means that overall capacity when both channels are active (i.e., on double-target trials) is equal to the simple average of the two channels acting alone (i.e., on upper- or on lower-position single-target trials). In a sense, a fixed amount of available capacity is distributed equally between the two channels when both must operate (on double-target trials). Note incidentally that parallel fixed capacity is identical to standard serial processing (Townsend & Ashby, 1983).

where $H_U(t)$, $H_L(t)$, and $H_{U,L}(t)$ are the integrated hazard functions calculated in the single- and double-target trials, respectively. Satisfying the race model inequality is consistent with unlimited or limited capacity ($C(t) \leq 1$); violating it is consistent with supercapacity ($C(t) > 1$). Because the capacity coefficient and the race model bound are transformations of the same data, it is not surprising that they constrain each other (Townsend & Honey, 2007).

The results with respect to the capacity coefficient are presented in Figure 2. A glimpse at Figure 2 reveals that all values are below unity with some approaching 0.5 (fixed capacity) at around $t = 500$ ms. Clearly, the system underlying performance with A and D as target and distractor was limited-to-fixed capacity.

In summary, the overall results in this condition reproduced those often reported in studies of redundant-targets detection. An advantage in detection with double targets was observed within the framework of a limited capacity system. The two targets were processed along separate channels and the RTE merely reflected the statistical advantage reaped by their concurrence.

The Condition With A and a as Target and Distractor

Errors did not exceed 3% across all displays (and did not exceed 5% for each participant). For RT, less than 1% of the trials had values beyond the boundaries (of 200 and 1,100 ms). Target identity (A, a), target location (upper, lower), and key assignment (right hand or left hand) did not make a difference ($F < 1$, $t < 0.5$, and $F(1, 42) = 2.7$, $p > .1$, respectively), nor did they interact with the number of targets presented in the display ($F < 1$ for all tests).

The mean RTs for redundant- and single-target displays were 451 and 484 ms, respectively, resulting in an RTE of 33 ms ($t(17) = 4.36$, $p < .001$, $\eta^2 = 0.626$). The displays without target yielded the slowest responses with a mean of 512 ms ($F(2, 51) = 10.09$, $MSE = 1,680$, $p < .001$, $\eta^2 = 0.283$).

As in the former condition, we again tested the race model inequality to tap the source of the RTE. The data points in Figure 3 reveal (minor) violations between 300 to 360 ms. In this region, the system is supercapacity. It is equally clear from Figure 3 that the

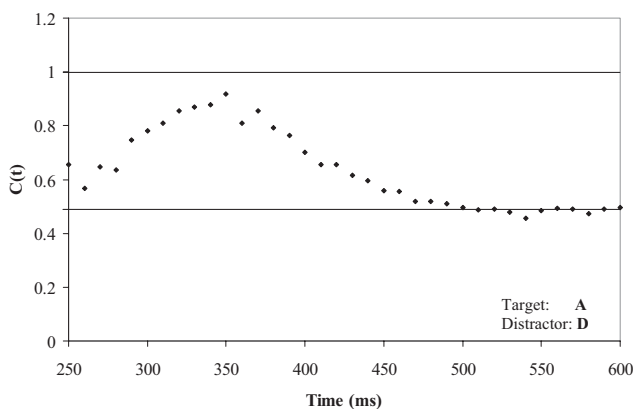


Figure 2. The capacity coefficient, $C(t)$, in the condition with A and D as target and distractor (Experiment 1). The points fall below unity (= unlimited capacity), approaching 0.5 (= fixed capacity) at around $t = 500$ ms. The system is limited-to-fixed capacity.

Grice bound was not violated. This means that capacity was not too severely limited in this condition with the letters A and a.

The evidence provided by the capacity coefficient in Figure 4 reinforces the trend evident in Figure 3. The data exhibit greater than unity values at around $t = 300$ ms, implying supercapacity at those short RTs. The results of the three tests converge in tapping a system of slightly limited to unlimited capacity at most times t.

Contrasting the Two Conditions of Experiment 1

Comparing performance across the pair of conditions used in the present experiment reveals the influence of a common name on detection. In both conditions, the target and the distractor differed physically from one another. However, a and A share names whereas D and A do not. The results show that this feature made a difference in detection and, possibly, in further properties of the system. First, name sharing slowed down detection a bit. It takes longer to detect the same target when its alternative goes by the same name than when it goes by a different name. The overall response means were 456 and 483 ms, respectively, in the first (A and D) and the second (A and a) conditions ($t(34) = 1.5$, $p = .1$, $\eta^2 = 0.061$). Second, the single reliable source of the slowdown was the single-target displays. For example, it took noticeably longer to detect target A in the pair Aa than in the pair AD. The difference between the sets of single-target displays in the two conditions amounted to 39 ms ($t(34) = 2.26$, $p < .05$, $\eta^2 = 0.130$); again, neither of the other displays produced a reliable difference across the two experiments. Third, associated with this difference is a parallel difference in the respective magnitudes of the RTE. The RTE in the second condition was almost three times its value in first ($t(34) = 2.43$, $p = .02$, $\eta^2 = 0.148$). The advantage accrued by exposure to replicas of a given signal is larger in an environment in which everything goes by the same name.

The last observation is consistent with the results of the distributional analyses. Commensurate with the different RTEs, the race model inequality was fully obeyed in the data with the letters A and D, but was sometimes violated in the data with the letters A and a. The Grice inequality was violated with the letters A and D, tapping regions of severe capacity imitations, but was satisfied when using the letters A and a. The capacity coefficient itself was quite low with the letters A and D, approaching fixed capacity through large windows of time, but was only slightly limited with the letters A and a (with the system sometimes evincing supercapacity). All the analyses converge on tapping a system that was somewhat less limited capacity when performing with A and a than when performing with A and D.

Conclusions

The collective results of Experiment 1 mandate the following conclusions. First, names are noticed and processed in tasks of visual target detection. They are extracted along with physical features upon the presentation of a stimulus. Second, name sharing impedes detection. If the signal and the distractor go by the same name, it takes the observer longer to detect the signal. Third, in situations in which the to-be-detected signal and the irrelevant distractor go by the same name, responses to displays with two signals (i.e., displays without distractors) are relatively very fast. Consequently, a large RTE is reaped in these situations. This large speedup with double targets may

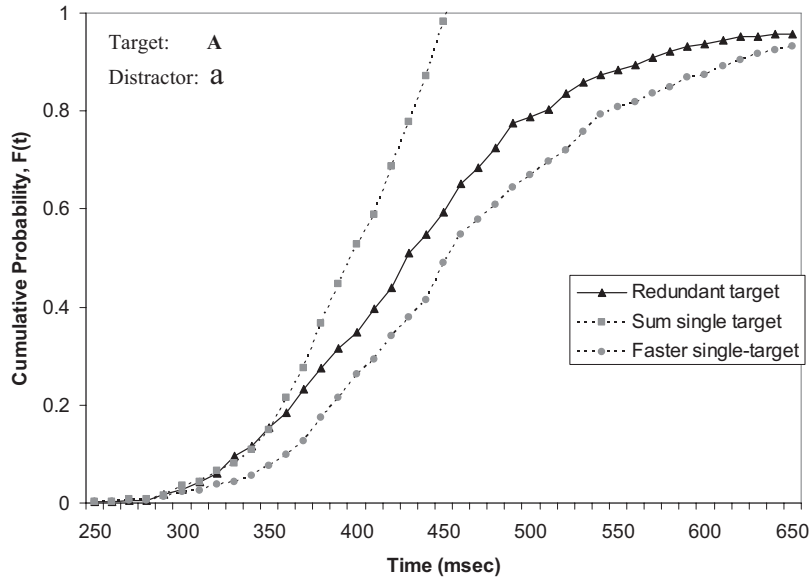


Figure 3. Tests of the race model inequality and the Grice bound in the condition with *A* and *a* as target and distractor (Experiment 1). The sum of the distribution functions for single targets crosses the distribution function for double targets at around $t = 320$ ms. Therefore, the race model inequality was violated at that time, indicating perhaps supercapacity in that region. The distribution function for the faster single target does not cross the distribution function for double targets. Therefore, the Grice bound was not violated.

well result from the absence of namesake distractors in the display, not necessarily from coactive processing of the two targets. Fourth, the existence of distractors bearing the name of the signals (even when absent from the particular display) engenders changes in the processing of the signals. Gauged by fine-grain analyses of capacity, signal processing is relatively more efficient in such an environment. To track the source of the augmented capacities found under conditions of name sharing, we examined whether it is the single targets (the denominator of the capacity formula) or the redundant targets (the numerator of the capacity formula) that generate the gain in $C(t)$. We found that whereas $H(t)$ diminished for the former, it increased for the latter. Nevertheless, performance with the single targets was more decisive in generating the enhanced capacity.

Given the weight of these results, we considered Experiment 1 to merit replication. We did so in an additional experiment with increased power in the framework of a within-subject design. The results obtained in this experiment with the same group of observers reproduced those observed with different groups of observers in Experiment 1.³

We also performed an auxiliary experiment to control for possible biases associated with the frequency of the various displays. Because each possible combination of the two letters was presented with equal frequency, those carrying a “Yes” response (single and double targets) comprised 75% of the trials. In the auxiliary experiment with a new group of 28 participants, we replicated the procedures of Experiment 1, but changed the relative frequency of the various types of trials. Double targets and single targets comprised 25% of the trials each (carrying a correct “Yes” response in 50% of the trials), and no-targets comprised the remaining 50% of the targets (with a correct “No” response). The results fully reproduced

those of Experiment 1 (as well as those of the additional experiment with a within-subject design).

In summary, investigators of visual detection should watch out for influence of nominal factors in their experiments. Physical features do not exhaust the effects of stimulus factors on detection. A joint examination of shared physical and nominal features (across targets and distractors) was the goal of the next experiment.

Experiment 2: Shared Names and Physical Similarity Between a Target and a Distractor

We increased the set of distractors to include letters that shared names or physical features with the target (as well as letters that were physically and nominally distinct from the target). We asked: How do shared names and/or physical features across targets and distractors impact detection? Do they impact performance to the same extent? We predicted an affirmative answer to both questions.

Method

Participants. An independent group of 32 young women and men participated in partial fulfillment of course requirement.

³ A fresh group of 32 participants performed in this experiment. To increase power further, *A* served as the sole target (given that target identity did not make a difference in Experiment 1). Each participant performed in two blocks, once with *a* and once with *D* as the distractor (with order of blocks counterbalanced across participants). The data and the full repertoire of analyses performed in this and all the subsequent (auxiliary) experiments mentioned in the article are available upon request from the authors.

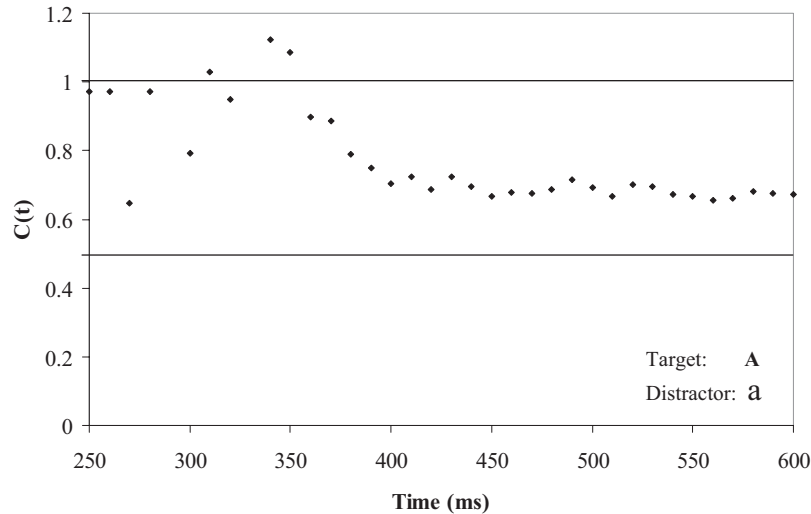


Figure 4. The capacity coefficient, $C(t)$, in the condition with A and a as target and distractor (Experiment 1). The greater than unity $C(t)$ values at around 300 ms might suggest supercapacity.

Stimuli and apparatus. The apparatus, stimulus presentation, and viewing conditions were the same as in Experiment 1. The stimulus set in Experiment 2 comprised the following four letters: the capital letters A and E and their lower-case formats, a and e (at the same visual size). All 16 pair-wise combinations (with replacement) of letters from this set were presented to the participant. Again, the stimuli used and the method of presentation was largely (though not fully) tailored after those by Grice and Reed (1992, Experiment 1).

This set of letters permits to assess the effect of name and of physical similarity: A and a , and E and e share names, whereas A and E , and a and e share physical features. Recall that, in general, letters in same-case format are rated higher on similarity than letters in different-case format (e.g., Boles & Clifford, 1989; Townsend, 1971).

One of the four stimuli, A , E , a , or e , served as the target for random quarters of the participants, with the other letters serving as distractors. Consider the group assigned A as the target. The double-targets stimulus was, of course, AA . The single-target displays included Aa , aA , AE , EA , Ae , and eA . The no-target or double-distractors displays were, aa , EE , ee , ae , ea , Ea , aE , Ee , and eE . The stimuli for the groups with the other letters as targets were created in a similar fashion.

Design and procedure. The design and procedure followed those of Experiment 1. Each observer was randomly assigned to one of four groups, with one of the four letters, A , a , E or e , defined as the target. A pair of letters was presented on each trial. The observer was asked to press one key ("Yes") if at least one of the letters in the display was the target and another key ("No") if none of the letters presented was the target. Key assignment was counterbalanced across participants in each subgroup.

The 16 stimulus displays were presented 12 times each, making for a total of 192 trials. An additional eight trials, presented first, served for practice (unbeknownst to the participant). The order of presentation was random and different for each participant. The experiment (as well as Experiments 3-5) started with instructions

that included eight demonstration trials with accuracy feedback to the participant on each trial. The experiment lasted approximately 15 min.

Results

Errors did not exceed 2.5% across all displays (and did not exceed 8% for each participant). The number of targets presented in the display (0, 1, 2) affected accuracy ($F(2, 93) = 7.73$, $MSE = 9.04$, $p = .001$, $\eta^2 = 0.143$). Accuracy in redundant-targets trials (99.3%) was higher than that for no-target trials (98%), which, in turn, was higher than that in single-target displays (96.3%). Responses slower than 1,200 ms and speedier than 200 ms were discarded as well (1.1% of the data). These boundaries were used in all subsequent experiments.

Target identity (A , a , E , or e) and key assignment did not make a difference ($F(3, 72) = 1.7$, $p > .1$, and $F < 1$, respectively), nor did they interact with the number of targets presented in the display ($F < 1$). However, target identity interacted with key assignment ($F(3, 72) = 3.25$, $MSE = 3,626$, $p = .03$), such that detection of capital letters was faster with the left-hand key, whereas detection of lower-case letters was faster with the right-hand key. Finally, detection was faster for targets in upper than in lower position in all conditions (means of 551 and 570 ms, respectively, $t(31) = 2.5$, $p = .02$, $\eta^2 = 0.169$).

The main result of Experiment 2 was the influence of *distractor* type on target detection. Because performance did not differ among the various targets, we present the entire data of Experiment 2 pooled across all targets and participants in Figure 5. Detection with redundant targets (mean of 501 ms) was faster than that with single targets (mean of 560 ms), the difference amounted to an RTE of 59 ms, on average ($t(31) = 11.7$, $p < .001$, $\eta^2 = 0.814$; the RTE was 40 ms for targets in favored locations, $t(31) = 8.29$, $p < .001$, $\eta^2 = 0.689$). The slowest responses were the "No" reactions to double distractors (mean of 577 ms; $F(2, 93) = 14.8$, $MSE = 3,487$, $p = .0001$, $\eta^2 = 0.241$). However, what is most

Target A, E, a, or e					
Redundant-targets (AA)					
501					
Single-targets with distractors sharing nominal/physical/no features with the target (A)					
	None (Ae)	Nominal (Aa)	Physical (AE)		
	548	562	571	560	
Distractor-distractor displays, sharing nominal/physical/no features with the target (A)					
None (ee)	Physical both distractors (EE)	Nominal both distractors (aa)	Physical (Ee)	Nominal (ae)	Physical & nominal (Ea)
495	519	546	585	589	577

Figure 5. Mean detection time (in milliseconds) pooled across the various stimulus combinations of Experiment 2. The letters in parentheses illustrate the combinations for the subset with A as the target.

revealing about these data is the difference in detection of the *same* target as a function of the accompanying distractor. When the distractor bore neither physical nor nominal semblance to the target (e.g., Ae with respect to target A), detection was fastest (548 ms). Replacing this distractor by one that shared the name of the target (Aa) slowed down detection (562 ms). Nominal identity thus took a toll of 14 ms on performance ($t(31) = 1.9, p = .07, \eta^2 = 0.097$). Substituting the nominally identical distractor with one with physical semblance to the target (AE) slowed down performance further (571 ms). Compared with the yardstick of a completely distinct distractor (Ae), physical similarity thus took a toll of 23 ms on detection ($t(31) = 2.97, p = .006, \eta^2 = 0.221$). Therefore, both shared names and physical semblance were detrimental to the detection of the target to roughly the same extent ($t(31) = 1.0, p > .1$).

Consider the complementary performance (speed of responding “No”) to pairs of letters that did not include the target. The fastest rejection (495 ms) was recorded when neither distractor shared nominal or physical features with the target (e.g., ee with respect to target A). All the other pairs of distractors shared at least one species of similarity with the target, a fact that slowed down the

response. Indeed, the slowest responding (642 ms) was recorded with pairs in which one letter was similar to the target physically and the other letter was identical to the target nominally (e.g., Ea). Distractor pairs in which at least one member bore physical similarity to the target (EE, Ee), or that shared name with the target (aa, ae) yielded increased latencies (means of 552 and 568 ms, respectively), although not as much as did pairs entailing both species of similarity (e.g., Ea). Overall, sharing at least one feature (physical or nominal) with the target slowed down performance to approximately the same extent ($t(31) = 8.2, p < .001, \eta^2 = 0.683$ and $t(31) = 8.8, p < .001, \eta^2 = 0.712$, respectively, for nominal and physical features). Of importance, too, presenting physical replicas of distractors, rather than a pair of disparate distractors, speeded-up rejection performance by 86 ms (means of 520 and 606 ms, respectively; $t(31) = 9.9, p < .001, \eta^2 = 0.760$).

We also conducted the distributional analyses of Experiment 1 for the data of Experiment 2 with each stimulus in turn as the target. The results were similar to those obtained in Experiment 1 with A and a as target and distractor: quite extended regions of super-capacity on the background of an otherwise unlimited capacity system. We attribute this pattern to the omnipresence in Experiment 2 of distractors sharing name and physical features with the target. Finally, in an auxiliary experiment performed on an independent sample of participants, we obtained the results of Experiment 2 when the probabilities of “Yes” and “No” trials were matched.

Conclusions

The presence of shared physical features between a target and a distractor slows down the detection of the target compared with a situation in which the two lack such features. This slowdown tends to be a bit larger than the parallel slowdown observed when the target and the distractor have a common name.

The two factors took a toll on the speed of responses to targetless displays, too. For these “No” responses, the nominal factor had a greater impact than the physical one. Figure 6 portrays the costs to performance for affirmation (in single target trials) and negation (in no-target trials) wrought by physical similarity and common names. The two species of distractors affected affirmation and negation differently ($F(1, 31) = 5.9, MSE = 771, p = .02$,

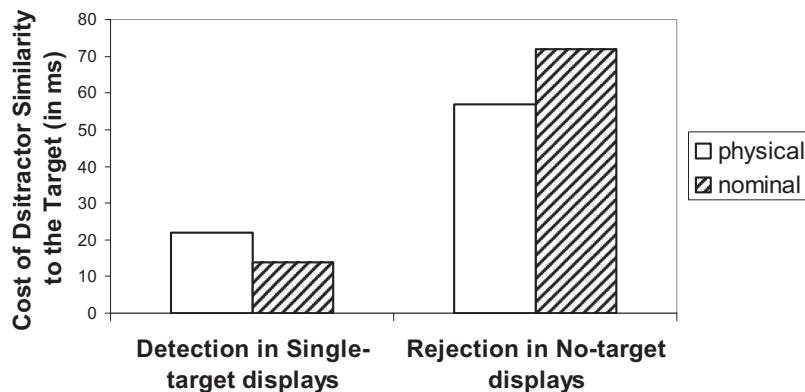


Figure 6. The cost (in milliseconds) of distractor similarity to the target for “Yes” responses in single-target displays and for “No” responses in no-target displays across all subsets (Experiment 2).

$\eta^2 = 0.434$). For the former, physical semblance had a slightly larger impact than common names (means of 22 and 14 ms, respectively; $t(31) = 1, p > .1$). For the latter, physical semblance had a smaller impact than common names (means of 57 and 72 ms, respectively; $t(31) = 2.1, p < .05, \eta^2 = 0.121$). We do not have a ready explanation for this difference and do not know whether it proves a general trend.

The results of Experiment 2 reinforce the conclusion that distractor composition influences target detection. Both physical and nominal factors are consequential, slowing down target detection or the decision that the target is absent from the scene. In the remaining experiments, we examine the effect of the two factors with target-target combinations (i.e., the emphasis is no longer on target-distractor combinations). Because Experiments 1 and 2 were concerned with the composition of distractors, a single stimulus always served as the target (e.g., *A*), and hence double targets always comprised replicas of this signal (*AA*). By contrast, in Experiments 3 through 5 different letters were included in the set of targets. As a result, double targets could comprise a pair of different letters (as well as replicas of the same letter). The observer's task was to detect the presence of either of these targets, or the absence of both. We asked: How does the composition of targets affect detection?

Experiment 3: Different Targets With the Same Name

Our goal in this experiment was to assess the effect on detection of physical similarity between the targets. To eliminate any influence of name, we always presented targets that went by the same name. We used the letters from Experiment 2, *A, E, a, and e*, but selected two with the same name (*A and a, or E and e*) to serve as targets. The remaining pair served then as the distractors. Consequently, double targets could be either completely identical (e.g., *AA*) or differ physically yet go by the same name (e.g., *Aa*). How does the physical composition of double targets affect detection?

Method

Participants. An independent group of 28 young women and men participated in partial fulfillment of course requirement.

Stimuli and apparatus. The apparatus, stimulus set, presentation, and viewing conditions were the same as those in Experiment 1. The difference was the composition of targets. Two letters with a common name from the set, *A, a, E, and e*, were defined as the targets. For a random half of the participants, *A and a* were the targets (and *E and e*, the distractors); for the remaining participants, *E and e* were the targets (and *A and a*, the distractors). Table 2 gives the classification of stimuli for the two groups.

Design and procedure. The design and procedure followed that of Experiment 1. Each observer was randomly assigned to one

of two conditions, with either *A and a* or *E and e* as targets. A pair of letters was presented on each trial. The observer was asked to press one key ("Yes") if at least one of the targets was present in the display and another key ("No") if none of the targets were presented. Key assignment was counterbalanced across participants in each group. Again, each display was presented 12 times for a total of 192 trials. An additional eight trials, presented first, served for practice (unbeknownst to the participant). The order of presentation was random and different for each participant. The experiment lasted approximately 15 min.

Results

Errors did not exceed 2.5% across all displays (and did not exceed 6% for each participant). The number of targets presented in the display (0, 1, 2) affected accuracy ($F(2, 81) = 11.56, MSE = 5.1, p < .001, \eta^2 = 0.222$). Accuracy for redundant targets (99.4%) was higher than for single targets (97.7%), which in turn was higher than that for no-target displays (96.5%). On single-target trials, there was an advantage for targets in the upper position (means of 580 and 615 ms, respectively, for targets in upper and lower position, $t(27) = 4.7, p < .001, \eta^2 = 0.121$). For RT, 1.0% of the trials exceeded the boundaries. Target set or key assignment did not make a difference ($F(1, 72) = 2.7, MSE = 5,228, p > .1$, and $F < 1$, respectively), nor did they interact with the number of targets presented in the display ($F < 1$).

The major finding of Experiment 3 was that physically identical (double-) targets were detected faster than physically different targets. Consider the subset of results with *A and a* as the targets (Figure 7). Detection with redundant targets (mean of 492 ms) was faster than that with single targets (mean of 579 ms), the difference amounted to an RTE of 87 ms ($t(13) = 9.2, p < .001, \eta^2 = 0.867$; the RTE was 76 ms with targets in the favored location, $t(13) = 8.1, p < .001, \eta^2 = 0.825$). The slowest responses obtained with the distractor-only displays (mean of 609 ms, $F(2, 39) = 8.25, MSE = 6,267, p = .001, \eta^2 = 0.297$). Again, our main focus was the composition of the redundant targets. Recall that all were identical nominally, but that *AA* and *aa* were also identical physically. For these double-targets, detection was fast (means of 483 and 475 ms, respectively, for *AA* and *aa*, $t(13) = 0.8, p > .1$). However, when the pair of redundant targets entailed only nominal identity (*Aa aA*), detection was noticeably slower (means of 504 and 506 ms, respectively). The introduction of a physical difference between redundant targets took a toll of 26 ms on detection on average ($t(13) = 4.3, p = .001, \eta^2 = 0.584$).

For various single-target displays, performance was similar except for the unusually fast detection with the stimulus *AE* (556 ms). The single-target displays were not diagnostic in this experiment because each included a distractor that held physical similarity with one of the targets.

Table 2
Allocation of Stimuli Into Redundant-, Single-, and No-Target Displays for the Two Subgroups of Experiment 3

Targets	Double targets	Single targets	No targets
A, a	AA, aa, Aa, aA	AE, EA, Ae, eA, aE, Ea, ae, ea	EE, ee, Ee, eE
E, e	EE, ee, Ee, eE	AE, EA, Ae, eA, aE, Ea, ae, ea	AA, aa, Aa, aA

Targets:	A, a				
Redundant targets:	AA 483	aa 475	Aa 505		492
Single targets:	AE 556	Ae 582	ae 586	aE 590	579
No targets:	EE 532	ee 542	Ee 682		609

Figure 7. Mean detection time (in milliseconds) for the various stimulus combinations in the subset with A and a as the targets (Experiment 3).

Considering the no-targets displays, one notes that the observers were fastest to reject physically identical distractors (EE, ee). The “No” responses to these stimuli averaged 537 ms, whereas those to Ee averaged 682 ms. Physically distinct distractors slowed down rejection by a hefty 145 ms ($t(13) = 10.4, p < .001, \eta^2 = 0.893$).

The complementary data with E and e as targets as well as the pooled data exhibited precisely the same trends (with all parallel effects similarly reliable).⁴ Finally, in an auxiliary experiment with a balanced distribution of “Yes” and “No” responses reproduced the results of Experiment 3.

Conclusions

The results of Experiment 3 speak to the issue of sameness and redundancy among targets. We presented targets, physically same or distinct, that went by a common name. Thus, we dissociated physical and nominal factors by keeping the latter constant. The main finding was that responding was faster to physically identical targets than to physically distinct targets. In a commensurate fashion, the RTE was larger for physically same than for physically different targets. Therefore, there is an appreciable advantage in detecting targets that are the same physically over and above the effect of the common names that such targets carry.

The present results are consistent with those reported by Grice and Reed (1992, Experiment 1) who found responses to identical target letters faster (by a reliable 9 ms) than responses to opposite-case target letters with the same name. There are several differences though between Grice and Reed’s (1992) and the present methods,⁵ the most consequential of which is the absence of distractors in the former. In the Grice and Reed (1992) study, targets were presented on all trials (alone, singly with a noise letter, doubly as full replicates, or doubly as opposite-case letters) with different responses assigned to the different classes of targets. This difference explains the appreciably larger advantage of physical identity (and the associated RTE) observed in the present study.

Following Mordkoff and Miller (1993), one ought to show that the unique advantage conferred by physical identity is not the result of

speedier processing of a specific favorite target (e.g., A or a). Consequently, we identified the less favored target for each of the 28 participants (e.g., a) and compared detection to same-target displays of the less favored target (e.g., aa) with that to mixed-targets displays (i.e., Aa and aA). We found that of the 28 observers, 21 detected mixed targets even slower than they detected the less-favored target (mean difference of 40 ms). Only seven participants detected mixed-targets faster than the less-favored targets (by an average of 25 ms). Together, these results support precedence for physical replicas.

Although the RTD is not always optimally suited to test serial versus parallel processing (Townsend, 1990), the advantage of AA over Aa as redundant targets may suggest (parallel-) interactive processing of the targets. The two targets must be pulled together in some way to generate the advantage of identical over distinct physical targets. In a serial mode of processing (with a minimum time stopping rule), the target that is noticed first produces the detection response. The same holds for an independent (parallel) race. According to the latter two models, replicas of the less-favored target are detected slower than mixed displays. The same-target advantage observed in Experiment 3 argues against both models.

In summary, there seems to be a unique advantage for physical identity in human information processing. Before drawing too firm conclusions though, recall that all targets in Experiment 3 shared names. Does physical identity carry the same advantage when the set of targets includes nominally different signals? The answer is not

⁴ In the pooled data of Experiment 3, the mean latencies for redundant- and single-targets were 506 and 598 ms, respectively, amounting to an RTE of 92 ms ($t(27) = 15.8, p < .001, \eta^2 = 0.902$; the RTE was 77 ms for targets in favored location, $t(27) = 11.9, p < .001, \eta^2 = 0.84$). Negation to double-distractors took 615 ms on average ($F(2, 81) = 19.76, MSE = 5,162, p < .001, \eta^2 = 0.311$). Again, detection was comparable with the various single-target displays. Concerning the consequential data with redundant targets, detection was fast when the signals were physical replicas (mean of 487 ms), but it was relatively slow when the signals differed physically from each other (mean of 525 ms; the difference favoring physical (hence total) identity was reliable, $t(27) = 5.0, p < .001, \eta^2 = 0.485$).

Considering the double-distractor displays, rejecting a pair of identical distractors took 546 ms, whereas rejecting a pair of physically different distractors took 684 ms, on average. Again, physically different distractors slowed down rejection appreciably (by 138 ms, $t(27) = 13.1, p < .001, \eta^2 = 0.865$).

⁵ A systematic comparison of Experiment 1 in Grice and Reed (1992) and Experiment 3 in the present study yields the following results. (a) stimulus set: The five letters, A, a, E e, and Y were used in the Grice and Reed study; the first four letters were used in the present study; (b) visual size: The letters differed in visual size in the Grice and Reed study, but were presented in the same visual size in this study; (c) stimulus duration: In the Grice and Reed study, the letters were presented briefly for 200 ms, preceded by an auditory warning cue. In this study, the presentation was response terminated, without warning; (d) stimulus allocation: In the Grice and Reed study, two letters comprised target-Set 1 (e.g., A, a), another two target-Set 2 (e.g., E, e), with the letter Y serving as a distractor. The participants gave one response if at least one of the targets in Set 1 appeared, and another response if at least one of the targets in Set 2 appeared. In this study, two letters were targets (e.g., A, a), and the other two were distractors (E, e). The participants gave one response if at least one of the targets appeared, and another if none of the targets appeared; (e) signals composition: The Grice and Reed study included eight double-target displays with the two targets associated with the same response, but did not include targetless displays. In this study, there were four double-target displays, and four targetless displays.

prima facie obvious. Grice and Reed (1992), who found an advantage of same-case letters over different-case letters with the same name (an advantage of *AA* over *Aa*; Experiment 1), have also found comparable performance for physically and nominally different targets and identical targets (comparable detection to *AD* and *AA*; Experiment 2). In point fact, Grice and Reed (1992) reported better detection to double-targets *AD* than to double-targets *AA* using a go-no-go response procedure. In Experiment 4, we pursued the issue further by including nominally different signals as targets.

Experiment 4: Different Targets

In Experiment 4 we again focused on the composition of (double-) targets. We replicated the design of Experiment 3 but this time the targets did not share names. They were either the capital letters *A* and *E* (for half of the observers) or the lower-case letters *a* and *e* (for the remaining half of the observers). Would a same-target advantage emerge in this experiment in which double targets no longer shared names?

Method

Participants. An independent group of 28 young women and men participated in partial fulfillment of course requirement.

Stimuli and apparatus. The apparatus, letter-set, presentation, and viewing conditions were the same as in Experiment 3. The difference was the definition of signals. For a random half of the participants, *A* and *E* were designated as the targets (and *a* and *e* were distractors); for the other half, the sampling reversed: *a* and *e* were the targets (and *A* and *E* were the distractors). Table 3 gives the classification of stimuli for the two subgroups.

Design and procedure. The design and procedure were the same as in Experiment 3, with the sole difference of target designation. Each observer was randomly assigned to one of two subgroups, with either *A* and *E* or *a* and *e* as targets. A pair of letters was presented on each trial. Key assignment was counterbalanced across participants in each subgroup.

Results

Errors did not exceed 3.5% across all displays (and did not exceed 8% for each participant). The number of targets presented in the display (0, 1, 2) affected accuracy ($F(2, 81) = 9.76$, $MSE = 2.0$, $p < .001$, $\eta^2 = 0.194$). Accuracy for redundant-, single-, and no-target displays was 98.9%, 97.2%, and 93.7%, respectively. For RT, 2.0% of the data points exceeded the boundaries. Target identity (*AE*, *ae*) did not make a difference ($F < 1$). Key assignment did ($F(1, 72) = 5.1$, $MSE = 8,071$, $p = .03$), with detection faster with the right-hand than with the left-hand key (583 and 627 ms, respectively). Neither target identity nor key assignment interacted with the number of targets presented in the display ($F < 1$ in both tests). Targets in an upper position were detected faster than targets in a lower position (means of 597 and 642 ms, respectively, $t(27) = 4.84$, $p < .001$, $\eta^2 = 0.465$), but position interacted with neither of the former variables ($F < 1$ in the two analyses).

The major finding of Experiment 4 was that pairs of physically identical targets were detected faster than pairs of physically (and

nominally) different targets. Consider the subset of results presented in Figure 8 obtained with the capital letters *A* and *E* as the targets.

Average detection with redundant targets (mean of 527 ms) was faster than that with single targets (mean of 610 ms), the difference amounting to an RTE of 83 ms ($t(13) = 12.5$, $p < .001$, $\eta^2 = 0.923$; the RTE was 57 ms for targets in favored location, $t(13) = 7.3$, $p < .001$, $\eta^2 = 0.822$). Again, the slowest responses were reserved for negation to no-target displays (mean of 673 ms, $F(2, 39) = 6.83$, $MSE = 10,470$, $p = .002$, $\eta^2 = 0.267$). Notice that all of the redundant-target displays included pairs of capital letters that bore, by virtue of this feature, *some* physical similarity to each other. However, *AA* and *EE* were identical physically (and nominally), whereas *AE* differed both in the physical and the nominal aspects. When the targets were physical replicas (*AA*, *EE*) detection was fast (means of 504 and 516 ms, respectively). Detection deteriorated when the two capital-letter targets were physically different (mean of 543 ms for *AE* or *EA*). Physical difference took a toll of 33 ms on performance ($t(13) = 2.9$, $p = .01$, $\eta^2 = 0.392$).

Detection times of single targets (the third row in Figure 8) were fairly similar except for the unusually fast detection with the *Ee* stimuli (mean of 593 ms). Single targets were not diagnostic in this experiment, too, because each included a distractor that was nominally identical to one of the targets (distractor *a* shared name with the target *A*, and distractor *e* shared name with the target *E*).

Notably, target-distractor relation within a (single-target) display did not affect performance. The distractor could carry the name of the target presented along with it (*Aa*, *Ee*) or that of the other, nonpresented target (*Ae*, *Ea*) but this feature did not make a difference (means of 602 and 618 ms, $t(13) = 1.6$, $p > .1$).

In the bottom row of Figure 8 (entailing the no-target stimuli), rejections were much faster for pairs of identical distractors (*aa*, *ee*, mean of 606 ms) than for distinct distractors (*ae*, mean of 740 ms; $t(13) = 9.1$, $p < .001$, $\eta^2 = 0.863$). Precisely the same pattern held for the subset of data with *a* and *e* as targets (recall that there was not an effect of target) and, consequently, for the pooled data.⁶

Again, matching the probability of the “Yes” and “No” trials in an auxiliary experiment did not make a difference. The results of Experiment 4 reappeared under the modified regime of trials.

⁶ In the pooled data of Experiment 4, the mean latencies for redundant- and single-target displays were 540 and 620 ms, respectively, yielding an RTE of 80 ms ($t(27) = 11.3$, $p < .001$, $\eta^2 = 0.824$; the RTE again was 57 ms for targets in favored position, $t(27) = 8.3$, $p < .001$, $\eta^2 = 0.708$). Rejections of double distractors yielded the slowest responses (with a mean of 653 ms, $F(2, 81) = 11.56$, $MSE = 8,068$, $p < .001$, $\eta^2 = 0.227$). Most important, the detection of redundant targets was fast when the targets were physical replicas of one another (mean of 521 ms), but it was slower for pairs of different targets (mean of 560 ms; the difference favoring total identity again was highly reliable, $t(27) = 4.4$, $p < .001$, $\eta^2 = 0.421$).

Single-target displays were detected at approximately the same speed. Notably, nominal sameness of the presented target-distractor pair did not expedite responding compared with pairs that lacked a common name (means of 616 and 625 ms, respectively, $t(27) = 1.6$, $p > .1$).

For double-distractors, rejection of a pair of physically identical distractors averaged 593 ms, whereas rejection of a pair of different distractors (in both appearance and name) averaged 717 ms (an advantage of 124 ms for replicas, $t(27) = 12.4$, $p < .001$, $\eta^2 = 0.851$).

Table 3
Allocation of Stimuli Into Redundant-, Single-, and No-Target Displays for the Two Subgroups of Experiment 4

Targets	Double targets	Single targets	No targets
A, E	AA, EE, AE, EA	Aa, aA, Ee, eE, Ae, eA, Ea, aE	aa, ee, ae, ea
a, e	aa, ee, ae, ea	Aa, aA, Ee, eE, Ae, eA, Ea, aE	AA, EE, AE, EA

Conclusions

The results of Experiment 4 are consistent with those of Experiment 3. Both experiments show that detection of identical targets is faster than that of different targets, regardless of whether the different targets have the same name (*Aa*, Experiment 3) or whether they bear physical similarity (*AE*, Experiment 4). This same-target advantage suggests parallel processing of the targets. Evidence accrued from the two replicas of a target coalesces somewhere to produce the fast response.

Considering Experiments 3 and 4 jointly, the same-target advantage—the difference in detection favoring same targets over different targets—did not differ between the experiments (38 and 39 ms; 26 and 33 ms for the subsets with *A* as the target, $F < 1$). *AA* enjoyed an advantage over *Aa* (Experiment 3) and over *AE* (Experiment 4) to roughly the same extent. Note that *Aa* and *AE* are special pairs of redundant targets themselves, sharing names or bearing physical similarity. They might (or might not) enjoy an advantage in detection when compared with redundant targets that possess neither of these properties. Nevertheless, total sameness is supreme even on the background of related targets—the gain reaped by complete identity is roughly the same when measured against nominal identity or against physical similarity. In Experiment 5, we compared directly, in a within-participant design, the detection of signals with different species of sameness or similarity.

Experiment 5: Identical Targets, Same-Name Targets, Physically Similar Targets, and Dissimilar Targets

In Experiment 5, we increased the set of targets to include the stimuli, *A*, *E*, *a*, and *e*. The composition of targets enabled four types of double-target displays: full physical replicas (e.g., *AA*), targets with the same name but that differ otherwise (e.g., *Aa*), targets that are similar physically but go by different names (e.g., *AE*), and fully distinct targets that share only semantic features (e.g., *Ae*). The set of distractors included the stimuli, *N*, *D*, *n*, and *d*. We created with these distractors precisely the same four types of similarity that we did with the targets. Note, too, that the set of targets differs from the set of distractors in the following respect. All of targets are vowels, whereas all of the distractors are consonants. Consequently, one can tell the presence of a target by attending to this semantic feature. Therefore, shared physical, nominal, and semantic features of targets were subjected to a comprehensive scrutiny in Experiment 5.

Method

Participants. A fresh group of sixteen undergraduates participated.

Stimuli and apparatus. The apparatus, stimulus presentation, and viewing conditions were the same as in Experiments 2 through 4. The stimulus set in Experiment 5 comprised the following eight letters: the capital letters, *A*, *E*, *N*, and *D*, and their lower-case forms, *a*, *e*, *n*, and *d* (again, all letters were presented in the same visual size). All 64 pair-wise combinations (with replacement) of letters from this set were presented to the participant.

The four vowels, *A*, *E*, *a*, and *e*, served as the targets, and the four consonants, *N*, *D*, *n*, and *d*, as distractors. The 64 pairs were classified into 16 double-target displays, 32 single-target displays, and 16 double-distractor (i.e., no-target) displays. Half of the letter-pairs were same-case pairs; the remaining half were different-case pairs. Table 4 gives the composition of trials in detail.

Design and procedure. The design and procedure followed those of Experiments 2 through 4. The vowels, *A*, *E*, and their lower-case counterparts, *a*, *e*, were designated as targets; the consonants, *N*, *D*, *n*, and *d*, were the distractors. A pair of letters was presented on each trial. The observer was asked to press one key if at least one of the targets appeared in the display and to press another key if none of the letters presented was a target.

The 64 stimulus displays were presented two times each, making for a total of 128 trials. An additional eight trials, presented first, served for practice (unbeknownst to the participant). The order of presentation was random and different for each participant. The experiment lasted approximately 15 min.

Targets:	A, E				
Redundant targets:	AA 504	EE 516	AE 543		527
Single targets:	Ee 593	Ea 619	Aa 612	Ae 616	610
No targets:	ee 600	aa 612	ae 740		673

Figure 8. Mean detection time (in milliseconds) for the various stimulus combinations in the subset of with the capital letters *A* and *E* as the targets (Experiment 4).

Table 4
Allocation of Stimuli Into Redundant-, Single-, and No-Target Displays in Experiment 5

Double targets	Single targets	No targets
AA, EE, aa, ee	AN, NA, AD, DA, EN, NE, ED, DE	NN, DD, nn, dd
Aa, aA, Ee, eE	an, na, ad, da, en, ne, ed, de	Nn, nN, Dd, dD
AE, EA, ae, ea	An, nA, Ad, dA, En, nE, Ed, dE	ND, DN, nd, dn
Ea, aE, Ae, eA	aN, Na, aD, Da, eN, Ne, eD, De	Nd, dN, Dn, nD

Results

Errors did not exceed 2.5% across all displays (and did not exceed 5% for each participant). Accuracy was comparable across target locations ($t < 1$). For RT, 0.7% of the data points exceeded the boundaries. The main results are presented in Figure 9.

Average detection of redundant targets (mean of 502 ms) was faster than that of single targets (mean of 579 ms), the difference amounting to an RTE of 77 ms ($t(15) = 8.7, p < .001, \eta^2 = 0.821$). The most interesting feature of data was the differences (or lack thereof) among the various double-target displays. When the targets were physical replicas (AA, EE, aa, ee), detection was fastest (mean of 471 ms). Detection took considerably longer with all the other combinations of double targets (mean of 512 ms; the advantage of total sameness was reliable, $t(15) = 4.13, p < .001, \eta^2 = 0.532$). Even in the case in which the targets shared names (Aa, Ee), detection was 39 ms slower than that to physical replicas ($t(15) = 2.9, p = .01, \eta^2 = 0.352$). In fact, targets that shared names or bore physical similarity did not lead to faster detection than targets that shared none ($F < 1$ for both comparisons).

For single-target trials, the physical semblance of the target and the distractor in the display did not affect performance. Detecting the target in AN, AD, EN, ED, or in an, ad, en, ed (all entailing some physical similarity) took approximately the same time as detecting it in An, Ad, En, Ed, aN, aD, eN, or eD (all physically dissimilar; means of 579 and 580 ms, respectively). Single-target displays in this experiment were not particularly interesting (nor diagnostic) because each included a distractor that held physical similarity with a target (whether or not presented along in that display).

In the bottom row of Figure 9 (entailing the no-target stimuli), the “No” responses were faster for pairs of identical distractors (mean of 573 ms) than for pairs of different distractors (mean of 681 ms; the advantage for total sameness with the distractors, too, was highly reliable, $t(15) = 7.4, p < .001, \eta^2 = 0.787$). Notably, rejection latencies were comparable for distractors that shared names (mean of 663 ms), for distractors that shared physical features (mean of 691 ms), as well as for distractors that shared none (mean of 688 ms; $F < 1$).

Conclusions

Physical replicas of a signal yielded faster detections than did distinct signals with the same name or signals that bore some physical similarity. The same results obtained for negations: They were fastest for physically identical distractors. In general, presentation of the same targets yielded faster detections than did any composition of mixed targets. Even a shared name did not alleviate the slowdown with physically different targets. The superiority of physical replicas implies parallel processing. Following a serial mode, no differences among the various types of double-target displays are expected.

The “No” responses to the double-distractor displays were noteworthy, too. Reaction times (i.e., rejection times) were particularly swift with distractors that were physical replicas (e.g., NN), a result that betrays a modicum of parallel processing. The rest of the double-distractor displays led to approximately equal latencies of rejections, even when the distractors shared name (Nn) or case (ND).

General Discussion

The present results highlight the role of names. Humans are probably the only species whose detection of signals in the environment is affected by the names attached to those signals. Critical delay in detection can occur when the to-be-detected target goes by the same name as to-be-ignored distractor. Simultaneously, the processing of the targets is relatively more efficient under such conditions. Another feature documented by the present data is the role of physical similarity. Animals share with humans this feature of visual target detection. When the signals and the distractors share salient physical characteristics, the detection of the targets is impeded. Similarity engenders the same slowdown in detection that does nominal sameness across targets and distractors. A natural explanation for the effect of target-distractor similarity is that it is a form of camouflage (Bjork & Murray, 1977): A target is difficult to notice when it is located next to a similar distractor. Our results indicate that shared names, too, act as a form of camouflage.

Targets				
A, E, a, e				
Redundant target displays with targets that share identity/name/physical-similarity/none				
Identity (AA)	Name (Aa)	Physical-similarity (AE)	None (Ae)	
471	510	516	510	502
Single targets with distractors that do/do not share physical features with the target				
	Physical (AN)	None (Ad)		
	579	580		579
Double distractor displays with distractors that share identity/name/physical				
Identity (NN)	Name (Nn)	Physical-similarity (ND)	None (Nd)	
573	663	691	688	681

Figure 9. Mean detection time (in milliseconds) for the various stimulus combinations in Experiment 5. The letter pairs in the parentheses are examples of the pertinent compositions.

Concerning the composition of the target set, a salient feature of the data is the supremacy of physical sameness. When multiple targets are reproductions of one another, they are detected very speedily. Two sources can account for the disproportionate performance with physically identical targets. First, such signals are identical at all conceivable levels of analysis: Physically identical stimuli look the same, go by the same name, are spelled the same way, and mean the same thing. No other set of signals carries such an engulfing interstimulus congruity. Second, the cognitive system is predisposed to detect (or otherwise compare or process) physically same stimuli at singularly high speeds. Our results favor this second explanation (supported by the exceptionally swift rejections of distractor-replicas), although the contribution of full congruity cannot be ruled out completely.

Finally, the capacity of the system that processes the targets has been shown to vary as a function of the identity of the distractors. That stimuli other than the signals affect the processing characteristics of the signals is intriguing. The data show that capacity is augmented under more demanding situations. We discuss in turn each of these main features of the data.

Detrimental and Beneficial Effects of Shared Names by a Target and a Distractor on Target Detection

Language cannot afford a separate name to the virtually endless variation of states of nature. The net result is that discriminably different signals often go by the same name (acquired through long-term learning). Our data show that this situation takes a toll on the speed of detection despite the fact that physical features define the target. Nevertheless, there is an unexpected bonus to performance in such situations. The gain to detection when only targets are present (in particular, replicas of a given signal) is relatively large. The quality of processing a target is not strained by the presence and processing of another concurrent target. The results are intriguing in another respect: The capacity of processing of the same signals is affected by the identity of the distractors despite the fact that the distractors do not play any direct role in signal processing. The hypothesis that the RTE is partly or fully accounted by the (trivial) fact that targets-only presentations do not include distractors (that can inhibit action) has been entertained in the past (Grice, Canham, & Gwynne, 1984; Eriksen, Goettl, St. James, & Fournier, 1989; Fournier & Eriksen, 1990). Our results show that the composition of the distractors (beyond their mere presence or absence) also affects signal processing in systematic ways. When the distractor goes by the signal's name, the processing of double signals is, relatively speaking, more efficient.

The Detrimental Effect of Physical Similarity Between a Target and a Distractor on Target Detection

Similarity between targets and distractors has been shown to hinder target detection in studies of visual search (Duncan & Humphreys, 1989, 1992), and our current data show a similar pattern of impairment within the RTD. The results of Experiment 2 show that physical similarity between the target and the distractor precipitates a slowdown in detection of the target that is similar in magnitude to that caused by shared names. The

results of Experiment 2 further show that target-distractor similarity also impedes the decision indicating the absence of the target in distractors-only displays. Name sharing is as potent a factor as physical similarity in the visual detection of a target's presence or absence.

Speedy Detection and Rejection With Physically Identical Targets and Physically Identical Distractors

When considering the relationship between *targets and distractors*, our data highlight the importance of nominal identity and physical similarity. In sharp contrast, these factors are inconsequential when considering only the target stimuli. Name sharing loses its power to affect detection when it concerns signals. So does physical similarity. Multiple targets that share names or physical features are *not* detected faster than targets that are distinct in these and further respects. Instead, what is most revealing about detection of multiple targets is the supremacy of physical identity. Physical replicas are always detected fastest. Physical similarity is also conducive to a slower detection compared with that attained with total identity.

The paramountcy of physical identity is revealed in another portion of the data, the negative decisions made to pairs of distractor stimuli. These decisions are disproportionately fast when the distractors are physical replicas. Throughout all portions of the data, the "No" responses to target-less displays were slower than the "Yes" responses to displays that contained at least one target—with a single notable exception. Detecting the absence of targets when the distractors were physical reproductions of one another was often faster than affirmative responses to the presence of a target.

Whence the power of physical sameness? According to a widely accepted account, humans are uniquely sensitive to the appearance of stimuli that are (nearly) exact copies on one another. Such stimuli are rare in nature (although less so in the word of manufactured products including the psychological laboratory) and hence they grab attention. Viewed as a group onto itself, the stimuli are not informative (one can be predicted completely from another) so processing can be unusually efficient. The idea of a singularly fast processor dedicated solely to the detection of identity has been entertained in the literature (with respect to the same-different judgment [SDJ] and the visual search tasks). In Bamber's (1969, 1972; see also Bamber, Herder, & Tidd, 1975) influential model, an early "identity reporter" is construed as an extremely fast parallel processor. It is dedicated to detecting "sameness" to the extent that it does not signal mismatches, and can only emit (very fast) "same" responses. Duncan and Humphreys (1989) suggest a similar mechanism in their "attentional engagement theory of search." This early mechanism is "parallel . . . and resource free" (Duncan & Humphreys, 1989, p. 445). The mechanism serves to group together identical or highly similar stimuli to form structural units for further analysis and action. The primacy of physical identity is similarly assumed and found in studies of SDJ (e.g., Posner, 1978; Posner & Snyder, 1975) and forms the cornerstone of the levels of processing idea. The current data indicate that a similar mechanism likely operates in situations captured by the RTD.

The Processing of Redundant Signals: The Role of Context

A contextual factor of import revealed in this study is the number of signals in the stimulus set. When more than a single signal in the set of items is defined as target, redundant targets can be reproductions of one of the signals *or* can be different signals. If many pair-wise combinations of targets can appear (Experiment 5), the processing might be a bit different than when a single pair of targets (reproductions of the signal) always appears (Experiment 1). Thus, redundant targets, AA, were processed somewhat differently (in a strictly separate fashion) when A was the single target in the set (Experiment 1) than when further pairs of targets were also presented (Experiment 5). When there are multiple forms of targets composition, redundant targets that are physical replicas of one another are processed in a singularly efficient way.

Capacity of Processing a Signal as Function of its Distractor

Our data suggest the intriguing possibility that the distractor—a stimulus or an attribute that should be neglected in producing the detection response—can influence the capacity at which the targets are processed. In Experiment 1, in which a

single target was operative, the capacity in processing replicas of this target (i.e., redundant targets) varied as a function of the distractor. When the target was clearly distinct from the distractor, then capacity was fairly to severely limited. However, when the same target was not that distinct from the distractor (by name and/or by appearance), then capacity surprisingly improved.

It is not *prima facie* clear how to calculate capacity in situations entailing multiple possibilities for double targets and double distractors. Nevertheless, we considered Experiments 2 through 5 and calculated capacity for redundant targets, AA (appearing in all four experiments) with respect to various target-distractor combinations that include A (see Figure 10). The results exhibit substantial regions of supercapacity in all cases. We attribute this outcome to the fact that in all cases the distractors shared some salient feature with the target. When the to-be-ignored distractor shares nominal and/or physical features with the target in the overall set, double targets are processed with improved efficiency.

Why is capacity augmented in situations in which the distractor (absent on double-targets displays!) shares name or some physical feature with the target? The solution to the mystery, we submit, is that modicum difficulty might energize the system to work at greater capacity. This minimum difficulty

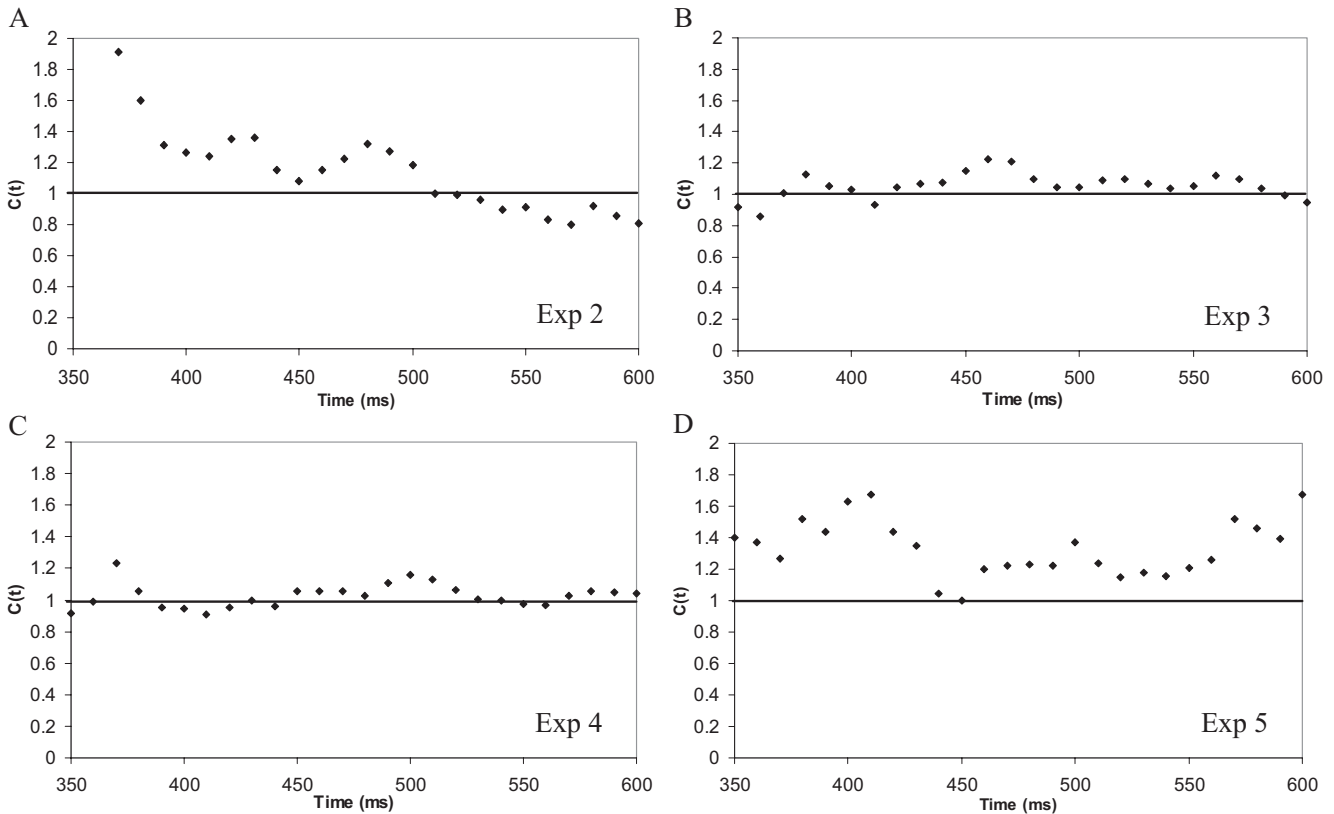


Figure 10. Capacity coefficients in Experiments 2 through 5 with respect to double targets AA and single targets entailing the target A. The distractors in the single target trials were *E*, *e*, and *a* in Experiment 2 (Panel A), *E* and *e* in Experiment 3 (Panel B), *a* and *e* in Experiment 4 (Panel C), and *N*, *n*, *D*, and *d* in Experiment 5 (Panel D). The greater than unity values in many regions might indicate supercapacity.

Table 5
User Guide for the Influence of Stimulus Factors in Visual Target Detection: Beneficial (+) and Detrimental (–) Effects of Nominal and Physical Features on Correct Detection of Targets or on the Decision on Their Absence

Factors	Display		
	Targets only	Targets and distractors	Distractors only
Name sharing	None	–	+
Name sharing with the absent distractor	–	NA	NA
Name sharing with the absent target	NA	NA	–
Physical similarity	None	–	+
Full physical replicas	+	NA	+

Note. NA = nonapplicable.

arises in situations in which the to be ignored alternatives are similar (in various respects) to the target. The difficulty thus created does not strain the system (the way it is strained with increases in the number of targets to be processed), but it just suffices to trigger the system to work more efficiently.

Conclusion

With a minimum of targets to detect and of distractors to ignore, humans are sensitive to the baroque compositions of their common and distinctive features. The distractors affect detection even in their absence! The present study highlights the role of complete physical identity and, in particular, of common names. In Table 5 we provide a “user guide” based on the most important findings of this study.

References

Ashby, F. G., & Townsend, J. T. (1986). Varieties of perceptual independence. *Psychological Review*, *93*, 154–179.

Bamber, D. (1969). Reaction times and error rates for “same”–“different” judgments of multidimensional stimuli. *Perception and Psychophysics*, *6*, 169–174.

Bamber, D. (1972). Reaction times and error rates for judging nominal identity of letter strings. *Perception and Psychophysics*, *12*, 321–326.

Bamber, D., Herder, J., & Tidd, K. (1975). Reaction times in task analogous to “same”–“different” judgment. *Perception and Psychophysics*, *18*, 321–327.

Besner, D., Coltheart, M., & Davelaar, E. (1984). Basic processes in reading: Computation of abstract letter identities. *Canadian Journal of Psychology*, *38*, 126–134.

Bjork, E. L., & Murray, J. T. (1977). On the nature of input channels in visual processing. *Psychological Review*, *84*, 472–484.

Boles, D. B., & Clifford, J. E. (1989). An upper- and lower-case alphabetic similarity matrix, with derived generation similarity values. *Behavior Research Methods, Instruments and Computers*, *21*, 579–586.

Brunsdon, R., Coltheart, M., & Nickels, L. (2006). Severe developmental letter-processing impairment: A treatment case study. *Cognitive Neuropsychology*, *23*, 795–821.

Colonius, H. (1990). A note on the stop-signal paradigm, or how to observe the unobservable. *Psychological Review*, *97*, 309–312.

Coltheart, M. (1981). Disorders of reading and their implications for models of normal reading. *Visible Language*, *3*, 245–286.

Coltheart, M., & Coltheart, V. (1997). Reading comprehension is not exclusively reliant upon phonological representation. *Cognitive Neuroscience*, *14*, 167–175.

Craik, F. I. M. (2002). Levels of processing: Past, present. . . and future? *Memory*, *10*, 305–318.

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*, 671–684.

Duncan, J., & Humphreys, G. (1992). Beyond the search surface: Visual search and attentional engagement. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 578–588.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review*, *96*, 433–458.

Egeth, H. E., & Dagenbach, D. (1991). Parallel versus serial processing in visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 550–559.

Egeth, H. E., & Santee, J. L. (1981). Conceptual and perceptual components in inter-letter inhibition. *Journal of Experimental Psychology: Human Perception and Performance*, *7*, 506–517.

Eriksen, C. W., & Eriksen, B. A. (1979). Target redundancy in visual search: Do repetitions of the target within the display impair processing? *Perception and Psychophysics*, *26*, 195–205.

Eriksen, C. W., Goettl, B., St. James, J., & Fournier, L. R. (1989). Processing redundant signals: Coactivation, divided attention, or what? *Perception and Psychophysics*, *45*, 356–370.

Eriksen, C. W., Morris, N., Yeh, Y., O’Hara, W. P., & Durst, R. T. (1981). Is recognition accuracy really impaired when the target is repeated in the display? *Perception and Psychophysics*, *30*, 375–385.

Evett, L. J., & Humphreys, G. W. (1981). The use of abstract graphemic information in lexical access. *Quarterly Journal of Experimental Psychology A*, *33A*, 325–350.

Eviatar, Z., Zaidel, E., & Wickens, T. (1994). Nominal and physical decision criteria in same-different judgments. *Perception and Psychophysics*, *56*, 62–72.

Farell, B. (1985). “Same” — “Different” judgments: A review of current controversies in perceptual comparisons. *Psychological Bulletin*, *98*, 419–456.

Fournier, L. R., & Eriksen, C. W. (1990). Coactivation in the perception of redundant targets. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 538–550.

Garner, W. R. (1962). *Uncertainty and structure as psychological concepts*. New York: Wiley.

Garner, W. R. (1974). *The processing of information and structure*. Potomac, MD: Earlbaum.

Garner, W. R. (1988). Facilitation and interference with a separable redundant dimension in stimulus comparison. *Perception and Psychophysics*, *44*, 321–330.

Grice, G. R., & Canham, L. (1990). Redundancy phenomena are affected by response requirements. *Perception and Psychophysics*, *48*, 209–213.

Grice, G. R., Canham, L., & Boroughs, J. M. (1984). Combination rule for redundant information in reaction time tasks with divided attention. *Perception and Psychophysics*, *35*, 451–463.

Grice, G. R., Canham, L., & Gwynne, J. W. (1984). Absence of a redundant-signals effect in a reaction time task with divided attention. *Perception and Psychophysics*, *36*, 565–570.

Grice, G. R., & Gwynne, J. W. (1987). Dependence of target redundancy effects on noise conditions and number of targets. *Perception and Psychophysics*, *42*, 29–36.

Grice, G. R., & Reed, J. M. (1992). What makes targets redundant? *Perception and Psychophysics*, *51*, 437–442.

Luce, R. D. (1986). *Reaction times: Their role in inferring elementary mental organization*. New York: Oxford University Press.

- Miller, J. (1982). Divided attention: Evidence for coactivation with redundant signals. *Cognitive Psychology*, *14*, 247–279.
- Miller, J. (1991). Channel interaction and the redundant–targets effect in bimodal divided attention. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 160–169.
- Miller, J., & Reynolds, A. (2003). The locus of redundant–targets and no–targets effects: Evidence from the psychological refractory period paradigm. *Journal for Experimental Psychology: Human Perception and Performance*, *29*, 1126–1142.
- Miniussi C., Girelli M., & Marzi C. A. (1998). Neural site of the redundant target effect: Electrophysiological evidence. *Journal of Cognitive Neuroscience*, *10*, 216–230.
- Mordkoff, J. T., & Egeth, H. E. (1993). Response time and accuracy revisited: Converging support for the interactive race model. *Journal of Experimental Psychology: Human Perception and Performance*, *19*, 981–991.
- Mordkoff, J. T., & Miller, J. (1993). Redundancy gains and co-activations with two different targets: The problem of target preferences and the effects of display frequency. *Perception and Psychophysics*, *53*, 527–535.
- Mordkoff, J. T., & Yantis, S. (1991). An interactive race model of divided attention. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 520–538.
- Mordkoff, J. T., Yantis, S., & Egeth, H. E. (1990). Detecting conjunctions of color and form in parallel. *Perception and Psychophysics*, *48*, 157–168.
- Pomerantz, J. R., Sager, L. C., & Stoever, R. J. (1977). Perception of wholes and of their component parts: Some configural superiority effects. *Journal of Experimental Psychology: Human Perception and Performance*, *3*, 422–435.
- Posner, M. I. (1978). *Chronometric explorations of mind: The third Paul M. Fitts lectures delivered at the University of Michigan* (Chapter 2, pp. 27–56). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Posner, M. I., Boies, S. J., Eichelman, W. H., & Taylor, R. L. (1969). Retention of visual and name codes of single letters. *Journal of Experimental Psychology*, *79*, 1–16.
- Posner, M. I., & Mitchell, R. F. (1967). Chronometric analysis of classification. *Psychological Review*, *74*, 392–409.
- Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola symposium* (pp. 55–85). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Raab, D. H. (1962). Statistical facilitation of simple reaction times. *Transactions of the New York Academy of Sciences*, *24*, 574–590.
- Santee, J. L., & Egeth, H. E. (1982). Independence versus interference in the perceptual processing of letters. *Perception and Psychophysics*, *31*, 101–116.
- Santee, J. L., & Egeth, H. L. (1980). Interference in letter identification: A test of feature-specific inhibition. *Perception and Psychophysics*, *27*, 321–330.
- Schwarz, W. (1989). A new model to explain the redundant signal effect. *Perception and Psychophysics*, *46*, 498–500.
- Theeuwes, J. (1994). The effects of location cuing on redundant–target processing. *Psychological Research*, *57*, 15–19.
- Townsend, J. T. (1971). Theoretical analysis of an alphabetic confusion matrix. *Perception and Psychophysics*, *9*, 40–50.
- Townsend, J. T. (1990). Serial vs. parallel processing: Sometimes they look like tweedledum and tweedledee but they can (and should) be distinguished. *Psychological Science*, *1*, 46–54.
- Townsend, J. T., & Ashby, F. G. (1983). *The stochastic modeling of elementary psychological processes*. Cambridge, UK: Cambridge University Press.
- Townsend, J. T., & Honey, C. (2007). Consequences of base time for redundant signals experiments. *Journal of Mathematical Psychology*, *51*(4), 242–265.
- Townsend, J. T., & Nozawa, G. (1995). Spatio-temporal properties of elementary perception: An investigation of parallel, serial, and coactive theories. *Journal of Mathematical Psychology*, *39*, 321–359.
- Townsend, J. T., & Nozawa, G. (1997). Serial exhaustive models can violate the race inequality: Implications for architecture and capacity. *Psychological Review*, *104*, 595–602.
- Townsend, J. T., & Wenger, M. J. (1999). Basic response time tools for studying general processing capacity in attention, perception, and cognition. *Journal of General Psychology*, *127*, 67–99.
- Townsend, J. T., & Wenger, M. J. (2004). A theory of interactive parallel processing: New capacity measures and predictions for a response time inequality series. *Psychological Review*, *111*, 1003–1035.
- Van der Heijden, A. H. C. (1975). Some evidence for a limited capacity parallel self-terminating process in simple visual search tasks. *Acta Psychologica*, *39*, 21–41.
- Van der Heijden, A. H. C., & La Heij, W. (1982). The array size function in simple visual search tasks: A comparison between “go–no go” and “yes–no” tasks under conditions of high and low target–noise similarity. *Psychological Research*, *44*, 355–368.
- Van der Heijden, A. H. C., & La Heij, W. (1983). The array size function in simple visual search tasks: A comparison between a “go–no go” and a “detection” task under conditions of low target–noise similarity. *Psychological Research*, *45*, 221–234.
- Van der Heijden, A. H. C., La Heij, W., & Boer, J. P. A. (1983). Parallel processing of redundant targets in simple visual search tasks. *Psychological Research*, *45*, 235–254.
- Van der Heijden, A. H. C., Schreuder, R., Maris, L., & Neerinx, M. (1984). Some evidence for correlated separate activation in a simple letter–detection task. *Perception and Psychophysics*, *36*, 577–585.
- Wenger, M. J., & Townsend, J. T. (2000). Basic response time tools for studying general processing capacity in attention, perception and cognition. *The Journal of General Psychology*, *127*, 67–99.
- Westendorf, D., & Blake, R. (1988). Binocular reaction times to contrast increments. *Vision Research*, *28*, 355–359.

Received May 27, 2007

Revision received September 9, 2008

Accepted September 21, 2008 ■