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Abstract. This paper describes two experiments using a masked priming method with 60 ms SOA. In the first experiment, the task was an alphabetical decision. The stimuli were isolated letters or non-alphabetical symbols, preceded by a similar or different prime, while the primes were scaled down or 180° rotated. Response times to letters revealed priming effects for both prime transformations. In the second experiment, the task was a lexical decision, and the stimuli were five lower-case letter words or pseudo-words. The priming conditions were similar to those of the first experiment. Response times to words revealed priming effects for both prime transformations, however the priming effect was only marginally significant for rotated primes and it appeared dependent on the frequency of use of the prime. A significant correlation between priming effects and the frequency of use of the different prime words was observed. We concluded that scale invariant features are used in the perception of letters and words as well, while 180° rotation invariant features are used in the perception of letters, but no such a conclusion can be drawn for words, in general.

Most stimuli we can perceive in our environment do not loose their identity whenever they are translated in the visual field, their size is modified, they are slanted or rotated to a certain extend. One says that the perception of these stimuli is invariant to the considered transformations. However, one must take care that all possible transformations do not have equivalent effects on the perception of any type of stimulus. Visual perception seems quite robustly invariant to translations and size variations, however the effect of transformations such as symmetries or rotations seems more variable, depending on the nature of the stimulus. For example, one can easily recognise a 180° rotated letter A, while recognising a 180° rotated familiar human face is not so evident. Understanding the nature of perceptual invariants is essential for suitably modelling shape recognition processes. One must not confound the idea of perceptual invariant with that of mental transformation. For example, well-known studies showed that mental rotations are gradual time-consuming operations whose duration depends on the angle of rotation (Cooper, 1975, 1976; Cooper & Shepard, 1973). If visual perception was invariant to rotations, in a general way, no such mental transformations would be necessary. Translation invariance provides a possible simple example. Assume that, before recognising a shape, the perception centres all points' coordinates on the centre of gravity of the shape. This provides translation invariance to the recognition process, while the complexity of the operation (theoretically) does not depend on the magnitude of the translation. A more general and realistic way of obtaining translation and scale invariance can be found in neuron-like models such as the so-called "Neocognitrons" (Fukushima, 1992; Fukushima & Imagawa, 1993; Fukushima, Miyake & Ito, 1983). Hence, a possible empirical support for distinguishing perceptual invariance from mental transformation is the time required for reducing the transformation, and its dependence on the magnitude of the transformation. We can reasonably speak of perceptual invariant whenever the transformation processing time is short and does not depend on the magnitude of the

transformation (at least in a non negligible range). Another problem results from the fact that quite complex stimuli can be analysed at various scales, resulting in perceptual components (features) of various sizes that do not necessarily exhibit a homogeneous behaviour with respect to transformations. Consider for example printed words' perception. One knows that words are recognised through their component letters (McClelland, 1976), however there are some reasons of thinking that more global features also contribute to word recognition, in parallel to component letters' recognition (Allen & Emerson, 1991; Allen & Madden, 1990; Lété & Pynte, 2003). Assume (for example convenience) that letter recognition, as well as word's global feature processing, are invariant to rotations, and a 180° rotated word is presented. Then global features are recognised, as well as individual component letters, however these ones appear in reversed order, that is, as an anagram of the word. Thus, a 180° rotated word can appear hard to recognise even if all its component features are rotationally invariants. On the other hand, if one presents a word where all letters have been individually 180° rotated, while their order is preserved, then the orthographic analysis suitably fit the word, however word's global features are broken down. The literature provides some interesting results concerning such manipulations. In particular, it was observed that globally 180° rotated words are easier to recognise than words whose letters have been individually 180° rotated (Navon, 1978; Tzelgov & Henik, 1983). In the above sketched perspective, this would mean that rotationally invariant global features play an important role in word recognition. However, this is not the conclusion of the authors, since the observed effects can also be interpreted in terms of a corrective mental rotation of the stimulus. In fact, the used word naming tasks do not allow for contrasting the corrective mental rotation hypothesis and the rotationally invariant feature hypothesis. Masked priming techniques are known to be much more suitable than simple recognition tasks to study early perceptual processes. In these methods, a prime stimulus is presented for a short duration (less than 100 ms), and then is

post-masked by a target stimulus on which the subject must perform a given task. The subject is usually not aware that he/she processed a prime, however this processing actually occurs and it can produce detectable effects on the processing of the target. Depending on the relations between the prime and the target, these effects can be either facilitating or inhibitory, they are detectable for prime durations of about 30 ms, and they increase up to prime durations of about 60 ms (Ziegler, Ferrand, Jacobs, Rey, & Grainger, 2000). Letter priming allowed for detecting scale invariance in the perception of letters, in a range of half-twice the target size (Petit & Grainger, 2002). Anagram priming (Courrieu, 1985), and orthographic priming (Humphreys, Evett, & Quinlan, 1990; Peressotti & Grainger, 1999) showed translation invariance of letters in words, while various hypothesis concerning letter order encoding have been proposed. Data obtained with other techniques such as unmasked priming and/or similarity judgement provided suspicion that certain letter global features could be invariant through symmetries or 180° rotations (Courrieu & De Falco, 1989; Courrieu, Farioli, & Grainger, 2004; Kimchi & Hadad, 2002), despite the fact that such invariants are not relevant for letter recognition since they lead to confuse letters such as b, d, p, and q. The main purpose of the following experiments is to test, using a masked priming technique, the hypothesis that letter and word recognition uses features that are invariant to 180° rotations. Well-known priming effects obtained with prime scale reduction will be used as reference effects in order to compare their magnitude to that of rotated prime effects.

Experiment 1

In this experiment, we used an alphabetical decision task (letter / non-letter) on target stimuli that were letters or non-alphabetical symbols. The target was preceded by a 60 ms duration prime that was nominally similar to or different from the target character. The prime

characters where smaller than the targets, or they were 180° rotated. If letter perception uses features invariant to 180° rotation, then one can expect that rotated primes provide priming effects of about the same magnitude as scaled down primes, that is, faster response times for nominally similar than for different primes in both cases of transformations. On the other hand, if there are no rotation invariant features, one can expect priming effects for scaled down primes (known effect), but not for rotated primes.

Method

Subjects. Forty university students with normal vision participated in Experiment 1 on a voluntary base.

Apparatus. Subjects were tested individually on a Macintosh computer, the experiment being driven by PsyScope 1.2.5 software.

Materials. A set of 16 upper-case letters was selected, with the constraint that none of these letters had the same shape when 180° rotated (H, I, O, X), or widely overlapped (N, Q, Z), or had a shape close to that of another letter (M/W, S/Z). The standard font Geneva was used, with size 14 for targets and rotated primes, and size 9 for scaled down primes. The same set of letters was used for primes and targets, which were paired in order to obtain 4 pairs for identical/scaled down priming condition, 4 pairs for different/scaled down priming condition, 4 pairs for identical/180° rotated priming condition, and 4 pairs for different/180° rotated priming condition. The pairing of primes and targets was varied using a Latin Square in such a way that each letter appeared in each priming condition, while a given subject saw a given target only once. A set of 16 non-alphabetical symbols was selected and paired in the same

way. In addition, 16 pairs of symbol-letter type and 16 pairs of letter-symbol type were used in order to avoid correlations between prime and target types in the experiment. The characters used for these non experimental pairs were different from experimental ones, as were those used for an initial practice session (10 pairs).

Procedure. Subject's eyes were at a distance of about 35 cm of the computer screen. First, an asterisk was displayed as a fixation point for one second. Then the asterisk was replaced by the prime for 60 milliseconds, and finally the target, which remained on the screen until the subject responded, replaced the prime. Subjects were instructed to respond as quickly and accurately as possible, by pressing a YES key at right if the target was a letter of the usual alphabet, or by pressing a NO key at left if the target was not a usual letter. The experiment began with 10 practice trials, followed by 64 trials in random and randomly varied order.

Data analysis. Response times (in ms) for letters and symbols were submitted to standard analysis of variance separately, without any data filtering. Each analysis of variance was performed for subject population (F1 ratios), and for (target) item population (F2 ratios). The four priming conditions were described by two factors with two levels each: the prime relation to the target (similar, different), and the prime transformation (scaled down, 180° rotated). The conditions of the Latin Square defined a secondary four levels factor, with ten subjects (subject analysis), or four items (item analysis) in each condition.

Results

Mean response times (and percents of errors) are presented in Table 1, together with the mean priming effects, that is the response time for different prime minus the response time for similar prime.

Letter targets. There was a significant main priming effect, that is, response times were significantly shorter with a similar prime than with a different prime ($F_1(1, 36)=12.529$, $p<.01$; $F_2(1, 12)=7.538$, $p<.05$). Subjects responded significantly faster when the prime was scaled down than when the prime was 180° rotated ($F_1(1, 36)=12.415$, $p<.01$; $F_2(1, 12)=5.769$, $p<.05$), no matter its relation to the target since there was no detectable interaction between the two main factors ($F_1<1$, $F_2<1$). This is the pattern expected if letters are perceived through features invariant to 180° rotation, except the main effect of the type of transformation which was not expected and will be discussed latter. Simple priming effects were also tested. The simple priming effect for scaled down primes was in fact not significant ($F_1(1, 36)=3.582$, $p<.07$; $F_2(1, 12)=1.356$, $p<.27$), however we know that this effect actually exists (Petit & Grainger, 2002, exp. 3). The simple priming effect for 180° rotated primes was significant in the subject analysis only ($F_1(1, 36)=9,873$, $p<.01$; $F_2(1, 12)=3,736$, $p<.08$). In fact, it seems that the random variance with unfiltered data was too large for allowing simple effects to reach conventional significance thresholds.

Table 1. Mean response times in milliseconds (and percents of errors) in Experiment 1.

	Similar prime	Different prime	Priming effect
Letters			
Scaled down prime	523 (2.5%)	554 (0.0%)	31 ms
180° rotated prime	564 (5.0%)	616 (4.4%)	52 ms
Symbols			
Scaled down prime	618 (3.8%)	632 (3.8%)	14 ms
180° rotated prime	605 (3.1%)	623 (1.3%)	18 ms

Symbol targets. None of the experimental factors provided detectable effects for this type of stimulus (F1<1 and F2<1 for all variation sources).

Discussion

The pattern of results corresponds to the one expected if letter perception uses some180° rotation invariant features, that is, priming is obtained with 180° rotated primes and is not weaker than priming with scaled down primes. An unexpected main effect of the type of transformation was obtained with letters, while no such an effect was observed with symbols. Letters with scaled down primes were recognised faster than letters with 180° rotated primes, no matter the relation between the prime and the target. This suggests an interference effect simply depending on the size of the prime, thus probably occurring at a low visual processing level. Why, however, symbol perception is not affected by this visual interference? In fact, a number of symbols are unusual, if not unknown, for most subjects, and the set of possible symbols is a priori not closed, while the usual alphabet is a well-known finite set. Thus subjects probably attempted to recognise only letters, responding NO whenever no letter was recognised after a certain delay. In such a case, the response time to symbols is in fact independent of any prime characteristic, as we have actually observed.

Experiment 2

Experiment 2 is a transposition of Experiment 1 to word recognition level, and the experimental reasoning is the same.

Method

The methodology is similar to that of Experiment 1, except that the task was replaced by a lexical decision (word / non-word), and stimuli were five lower-case letter words or regular pseudo-words. The log-frequency of use of words ranged from 2.944 to 10.585, on a scale where the most frequent word in French (preposition "de") has a log-frequency of 14.563.

Results

Mean response times (and percents of errors) are presented in Table 2, together with the mean priming effects.

Word targets. Response times were shorter with a similar prime than with a different prime, the main priming effect being significant in subject analysis ($F_1(1, 36)=7.928$, $p<.01$), but only marginally significant in item analysis ($F_2(1, 12)=3.412$, $p<.09$). Subjects responded significantly faster when the prime was scaled down than when the prime was 180° rotated ($F_1(1, 36)=16.975$, $p<.001$; $F_2(1, 12)=15.858$, $p<.01$), no matter its relation to the target since there was no detectable interaction between the two main factors ($F_1<1$, $F_2<1$). This fit the pattern expected if word perception uses certain global features invariant to 180° rotation. Simple priming effects were also tested. The simple priming effect for scaled down primes was quite clearly detectable ($F_1(1, 36)=4.493$, $p<.05$; $F_2(1, 12)=4.744$, $p<.06$), however the simple priming effect for 180° rotated primes was not clear ($F_1(1, 36)=2.452$, $p<.13$; $F_2(1, 12)=2.589$, $p<.14$).

Pseudo-word targets. Subjects responded significantly faster when the prime was scaled down than when the prime was 180° rotated ($F1(1, 36)=24.92$, $p<.001$; $F2(1, 12)=15.16$, $p<.005$), and this was the only significant effect for pseudo-words.

Table 2. Mean response times in milliseconds (and percents of errors) in Experiment 2.

	Similar prime	Different prime	Priming effect
Words			
Scaled down prime	602 (3.8%)	643 (5.6%)	41 ms
180° rotated prime	650 (1.3%)	680 (3.8%)	30 ms
Pseudo-words			
Scaled down prime	680 (1.3%)	717 (0.6%)	37 ms
180° rotated prime	758 (3.1%)	765 (5.0%)	7 ms

Discussion

The pattern of results for words is quite similar to that observed for letters in Experiment 1. Thus a plausible conclusion could be that there are some 180° rotation invariant global features in the perception of words as well as in that of letters. However, results are not so clear. First, it seems that priming effects widely depend one some uncontrolled item characteristics, since these effects were not significant in item analysis. Second, while scaled down prime effects were clearly detectable in this experiment, the effect of 180° rotated primes remains questionable, according to the analysis of simple effects. An important characteristic of words is their frequency of use. Thus we computed the correlation between the log-frequency of the 16 target words and the main priming effect on these words, which resulted in a very low correlation ($r=.003$). The correlation between target's log-frequency and scaled down priming effect was $r= -.02$, while this correlation was $r= .02$ for rotated priming effect. In other words, priming effects do not depend on the frequency of use of target words. By chance, there was no correlation between the log-frequency of use of target words

and that of their associated different prime words in the experiment (r= -.067). Then we computed the correlation of the main priming effect with the log-frequency of the different prime word, which provided r= .50, p<.05. The correlation with the log-frequency of the different prime word was r= .38 for scaled down priming, and r= .47 for rotated priming. Thus a possible explanation is that priming effects mainly resulted from inhibitory effects generated by the most frequent different prime words only. As for letters in Experiment 1, rotated primes produced stronger forward masking effects than scaled down primes, no matter their relation to the target. This effect was detectable for non-words as well as for words, despite the fact that non-words must not be recognised (as symbols in Experiment 1). This is probably because orthographic features (letters) of non-words must be recognised before attempting to access the mental lexicon.

Conclusion

Masked priming effects were obtained on letters with scaled down primes (known effect), and 180° rotated primes as well. This implies that letter perception uses some features invariant to 180° rotation. A similar pattern of results was observed with word stimuli, however the effect of scaled down primes was clearly detectable, while the effect of rotated primes was only marginally detectable. Moreover, it was observed that word priming effects critically depended on the frequency of use of the prime. It seems that priming effects generated by transformed primes are obtained only when the different prime is a frequent word. This suggests that only the most frequent words can be activated by a transformed prime in a delay of 60 milliseconds. Thus, if there are global features invariant to 180° rotation in the perception of words, this probably concerns frequent words only. Further investigations are needed for confirmation and clearly understanding the involved mechanisms.

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