VISUAL COGNITION, 2004, *11* (8), 947–963

A new look at the relationship between perceptual and motor responses

Florian Waszak

Laboratoire de Psychologie Expérimentale, CNRS and René Descartes University, Boulogne-Billancourt, France, and Max Planck Institute for Human Cognitive and Brain Sciences, Department of Psychology, Munich, Germany

Andrei Gorea

Laboratoire de Psychologie Expérimentale, CNRS and René Descartes University, Boulogne-Billancourt, France

A visual stimulus may affect a motor response although its visibility is prevented by a mask. This implies that the sensorimotor system is more susceptible to stimulation than the perceptual system. We report data that are contrary to this intuition. Experiments where both the observer's perceptual state related to the presence/absence of a masked stimulus and the motor behaviour elicited by the same stimulus were jointly assessed on a trial-by-trial basis show that masked visual stimulation at constant visibility (d′) has two types of effect on the motor system. When the physical energy of the masked stimulus is weak, it affects the motor response only if it exceeds the observer's perceptual response criterion. It is only when the physical energy of the masked stimulus is relatively strong that its impact on the motor response is independent of the state of the perceptual system. This indicates that reflex, ''nonconscious'' behaviour has a high energy threshold.

The relationship between sensory-perceptual and sensorimotor processes has been debated for more than a century. It is indisputable that many actions are planned, prepared, and guided by visual information. But it is still unclear precisely how the perceptual analysis of visual stimuli relates to motor processes performed in reaction to this information. Folk psychology assumes that conscious visual experience—i.e., the endpoint of the visual analysis—is an indispensable precondition for the control of visuomotor behaviour. However, the last few decades witnessed a significant outgrowth of experimental paradigms challenging the assumption that visuomotor performance is exclusively

---

Please address all correspondence to Florian Waszak, Max Planck Institute for Human Cognitive and Brain Sciences, Department of Psychology, Amalienstraße 33, D-80799 Munich, Germany. Email: f.waszak@gmx.net

http://www.tandf.co.uk/journals/pp/13506285.html DOI: 10.1080/13506280444000003

guided by visual information that is present in conscious perceptual experience (see Rossetti & Pisella, 2002). For example, pointing movements toward visual stimuli, which are displaced during the action, seem to remain accurate even if the observer cannot report the displacement verbally when it is synchronized with a saccade (Bridgeman, Lewis, Heit, & Nagle, 1979; Desmurget, Prablanc, Rossetti, & Arzi, 1995). Moreover, Aglioti, DeSouza, and Goodale (1995) observed that, when subjects grasp the central circle of Titchener's illusion, grip size is largely determined by the true size of the circle to be grasped and not by its illusory size (see also Bridgeman, Kirch, & Sperling, 1981; Gentilucci, Chieffi, Daprati, Saetti, & Toni, 1996, for other examples of the motor system being little affected by visual illusions). Similarly, in the phenomenon of ''blindsight'', patients with lesions of the primary visual area (V1) are able to orient their eyes and/or hand to visual stimuli briefly presented within their ''blind'' field (see Weiskrantz, 1986).

Results of this kind have been related to the existence of two distinct visual systems in the brain—the dorsal and ventral pathways for sensory-perceptive and sensorimotor behaviour, respectively (the ''two visual systems hypothesis''; see Milner & Goodale, 1995; Ungerleider & Mishkin, 1982). Alternatively, the observed dichotomy in visual sensorimotor processing could be due to ''automatic'' visually guided behaviour, on the one hand, and visual awareness, on the other, being mediated by feedforward and by recurrent processing respectively (Enns & DiLollo, 2000; Lamme, 2001; Lamme & Roelfsema, 2000). Independently of the justness of either of the two accounts above, the general claim of nowadays research is that humans possess a kind of ''automatic pilot'' able to control actions towards visual targets online, irrespective of the observer's perceptual response to the stimuli. Consequently, much more is ''known'' about the dissociation than about the interaction between sensorimotor and sensory-perceptive processes.

The current debate on the alleged independence of motor and perceptual processes draws heavily on the frequently used paradigm of ''unconscious'' action priming. In the action priming paradigm with masked primes, observers are presented in rapid succession with two stimuli: a first (masked) stimulus and a second (backward masking) stimulus. Importantly, the visibility of the masked stimulus is hampered or even prevented by the second masking stimulus (Breitmeyer, 1984). The finding that masked stimuli can modulate the motor response to the stimulus pair despite not being consciously perceived by the observer (as it is masked by the masking stimulus; e.g., Ogmen, Breitmeyer, & Melvin, 2003) has been taken as evidence for the action system having access to information of unseen stimuli. Klotz and Neumann (1999) demonstrated that unrecognized primes facilitate or inhibit *choice* reactions to the mask if prime and mask share stimulus attributes critical for the correct or the alternative response, respectively (see also Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). Moreover, Ogmen et al. (2003) and Taylor and McCloskey

(1990), who investigated the triggering of preprogrammed *simple* motor responses to masked and unmasked stimuli, found that motor response times were not affected by whether or not a stimulus was masked.

None of the studies having explored this issue thus far analysed the response of the motor system in direct relation to the state of the perceptual system. This is the topic of the present study. Moreover, the present backward masking paradigm was meant to discriminate between two distinct accounts of the impact of a masked stimulus on the motor system, viz. whether it results from a mere facilitation of the motor response (to the masking stimulus), or whether it actually triggers the motor act. This paradigm allows the assessment both of the observer's perceptual state related to the presence/absence of a near-threshold stimulus and of the motor behaviour elicited by the same stimulus on a *trial-by-trial* basis.[1] On any given trial the response time (RT) to the occurrence of any of two (masked, S1, and masking, S2) stimuli was recorded together with the observer's subsequent response on the presence/absence of the (weaker, close to threshold) masked stimulus. For each observer, the separate analysis of his/her verbal (decisional) report on the presence/absence of a masked stimulus (presented within the standard Signal Detection Theory—SDT—format; Green & Swets, 1966) allowed the assessment of both the observer's sensitivity (d') and response criterion (c) indices. Moreover, analysing the observers' RTs to a masked + masking stimulus pair for each of the four standard response categories under SDT (hits, false alarms, misses, and correct rejections) allowed the study of RTs as a function of both the presence/absence of the relevant stimulus and the observer's internal state. The parametric manipulation of the masked stimulus strength (i.e., contrast/energy, hence d') and of its probability of occurrence (hence of the response criterion, c) permitted the assessment of the impact of the stimulus' visibility proper and of the observer's response criterion (decisional behaviour) on the RT. Finally, the use of a short and of a long mean S1–S2 stimulus onset asynchrony (SOA) coupled with carefully adjusted S1 strengths so as to keep S1 sensitivity constant allowed the assessment of stimulus energy proper on RT for identical sensory (d' and c) states.

To summarize, subjects were presented with a masked stimulus (S1; presented with a variable probability) and a mask (S2) that hampered the perception of the masked stimulus. Subjects were asked to perform a speeded simple response to the onset of any of the two stimuli. Subsequently, they were required

---

[1] Klotz and Neumann (1999), among others, signal out the possibility that the assessment of response times and detection performances within the same trial may yield typical dual-task interference effects. However, these same authors show that in a task of their own equivalent to the present one response time and perceptual performance are the same as obtained in a control experiment where the two performances were measured separately. In any event, a putative impairment of the observer's detection efficiency by a prior speeded response would be critical if one's purpose were to assess response time at $d' = 0$. This was not a purpose in the present experiments.

to indicate whether or not they perceived S1. S1 strength (hence d′) and S1 probability of appearance (hence c) were independently varied thereby allowing the assessment of the subjects' motor behaviour as a function of both d′ and c. The basic (but not the only) question asked was whether the response of the sensorimotor system (as measured by RT) was the same for any given d′ and c regardless of whether or not subjects reported S1 (hits and misses, respectively) and independently of the stimulus' physical energy.

GENERAL METHODS

The two experiments described in this study used the same stimuli and very similar experimental procedures. Here all the methodological details are given for Experiment 1. The very few differences characterizing Experiment 2 will be described before the presentation of the results obtained in this second experiment.

Stimuli

The stimuli were displayed at a 173 Hz frame rate on a Iiyama Vision Master Pro 454 colour monitor. Stimulus presentation and response recording were controlled by custom-made software. The starting point of the experiments was a standard metacontrast procedure. During the whole trial a fixation cross was present in the upper part of the screen. In each trial two visual stimuli were presented in rapid succession: A first (masked) stimulus (S1, a Gaussian luminance increment) presented within a bright, highly visible annulus (metacontrast) stimulus (S2) presented at variable stimulus onset asynchronies (SOA) with respect to S1 (backward masking). S1 was presented for 12 ms 4° below fixation. S2, the annulus, had sharp edges, an outer diameter of 0.4°, and it was presented for 36 ms at the same location as S1. Both stimuli were presented on a 47 cd/m^2 grey background at a distance of about 100 cm.

Procedure

Figure 1 illustrates the sequence of events in one trial. Observers were presented with (1) a random blank interval within a 200–1000 ms range; (2) a fixed blank interval of 108 ms, the beginning of which was taken as the reference time T0; (3) S1 (of variable contrast C; see below) with occurrence probabilities of 0.2, 0.5, or 0.8 at a random point in time (t_{S1}) within the interval [T_{108}–T_{198} ms]; (4) S2 at a random point in time (t_{S2}) within the interval [T_{270}–T_{360} ms]. The S1–S2 SOA being given by t_{S1}–t_{S2} (which were random variables), it varied randomly between 72 and 252 ms with a mean SOA of 162 ms.

Both the detectability of S1 (the masked stimulus) and its influence on the RT to the stimulus pair were measured. To do so, observers had two consecutive tasks: (1) To press a key on the response pad as fast as possible and as soon as

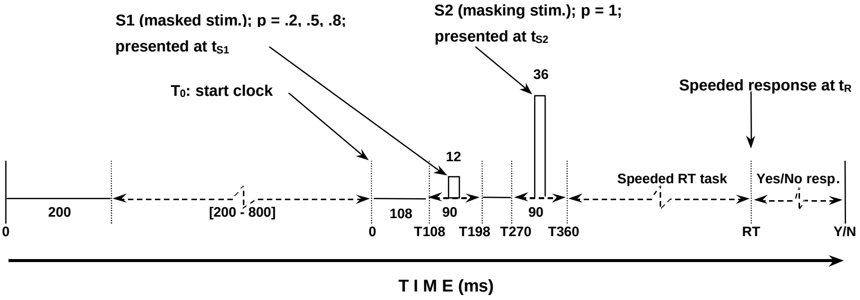

Figure 1. Timing of one trial.

they detect *any* luminance change (that is as soon as they detected either S1 or S2); (2) to indicate, after the speeded response, whether they saw S1 or not (by pressing one of two keys on the response pad); for this second response observers could take as much time as needed.

Note that the motor response time, t_R (also referred to as time point of reaction) was quantified by measuring the observers' response with respect to the reference time T_0 which was more or less arbitrarily chosen. The reason for this procedure was twofold. First, only measuring the response with respect to a fixed time point (rather than with respect to the onset of S1) made the correlation analysis (described below) possible. Second, it allowed the comparison of t_R–s for trials where S1 was absent with t_R–s for trials where S1 was present.

In Experiment 1, the contrast of S1 was contingent on the S1–S2 SOA so as to keep the sensitivity (d') to S1 constant. The specific contrasts to be used were determined for eight different SOAs (spanning the whole range of the SOAs actually used) and for each observer in two distinct pre-experiments. First, a 2AFC staircase procedure (1 UP–2 DOWN) tracked the observers' S1 thresholds (at 71% correct responses) in the presence of S2 for each of the eight SOAs. Based on this first threshold estimates (yielding a d' of about 0.8; Macmillan & Creelman, 1991), additional experiments were run with a constant stimuli method to assess d's (plural form of d') for a range of contrasts about the estimated detection thresholds. The aim was to find contrasts for each of the eight SOAs yielding d's of about 0.5, 1, and 2. A polynomial was fitted to the data of each observer relating his/her contrasts yielding a constant d' and the corresponding SOAs. This allowed the interpolation of contrasts (yielding the same d') for nontested SOA values. Hence, for each observer, the pre-experiments determined three *iso-sensitivity* functions indicating for each possible SOA the contrasts with which S1 was to be presented in order to yield d's of 0.5, 1, and 2. Contrasts were in the range of 0.08 to 0.26 (mean %-increments with respect to the 47 cd/m^2 grey background).

The main experiment was run in blocks of 300 trials each. One block was specified by the probability of occurrence of S1 (p = .2, .5, or .8) and by its predetermined contrast yielding d’s around 0.5, 1, 2. In addition, S1 was also presented with the maximum possible contrast for which they were perfectly visible for all the S1–S2 SOAs.[2] This experimental format yields 3[p] × 4[d′] = 12 distinct blocks. Each block was repeated at least three times in a random order obtained as a subset of a Latin square established for each observer.

In summary, in the main experiment S1 visibility proper and the observer’s response criterion (by manipulating the probability of S1 occurrence) were independently varied (by means of manipulating S1’s contrast and occurrence probability, respectively), with the SOA randomly changing from trial to trial. At the same time, we quantified the impact of S1 on the motor system by measuring t_R. t_R–s were analysed for each observer, each experimental block type (that is for four d′s and three S1 probabilities of occurrence) and for each response category under SDT: Hits (S1 present and reported as being present), false alarms (S1 absent but reported as being present), misses (S1 present, but reported as being absent), and correct rejections (S1 absent and reported as being absent). This allowed the study of the motor system’s response to S1—measured by t_R—as a function of both the presence/absence of S1 and the observer’s internal state (S1 reported as being present or absent).

Moreover, randomly and independently jittering the presentation times of S1 (t_{S1}) and S2 (t_{S2}) permitted the computation of the correlation between t_{S1} and the point of time of the observers’ reaction (t_R) (r_{tS1-tR}), on the one hand, and between t_{S2} and t_R (r_{tS2-tR}), on the other hand.[3] This analysis was intended to discriminate between two distinct accounts of the impact of a masked stimulus on the motor system, viz. whether it is due to the mere contrast enhancement of S2 as a consequence of the S1–S2 spatiotemporal summation, or to the direct triggering of the motor response by S1. In the latter case, so the reasoning goes, r_{tS1-tR} should be high, whereas r_{tS2-tR} should be low or zero. The mere observation that the presence of S1 yields shorter RTs does not exclude the following two possibilities: (1) That the shortening is due to the mere enhancement of S2 due to its summation with S, or (2) that S1 attracts attention to the location where S2 will be presented and, therefore, facilitates the perception of S2.

---

[2] For the ‘‘highly visible’’ condition, S1 was presented with the maximum available contrast with our set-up. Although observers noted having always seen this stimulus, the computation of its d′ was possible given that observers made nevertheless a very few response errors (FA, misses) of which they were aware. As a consequence, these high d′ values should not be taken seriously (they should be in fact infinite) and have not been used in the present analysis of t_R for FAs and misses.

[3] Note that t_{S1}, t_{S2}, and t_R are measured in reference to T_0.

Observers

The two authors (FW and AG) and one naive observer (SD) participated in Experiment 1 and only the first two in Experiment 2.

RESULTS

Experiment 1

Figure 2 shows mean time points of reaction (t_R) for each of the three observers (the three panel columns) as a function of S1 visibility (d′) with the occurrence probability of S1 as a parameter (the three panel rows as referred to by the outermost left labels) and for each of the four response categories under SDT (different symbols; see lower inset and caption). Inserts at the bottom left of each panel give observer's response criterion (c′) as it was actually measured. The results are clear-cut. t_R–s decrease with increasing d′, *but only for Hits*:[4] Only stimuli exceeding the perceptual criterion bear on the motor response! This is the case for all levels of probability of occurrence of S1, i.e., regardless of whether observers use a loose response criterion (reporting S1's presence for relatively weak internal responses; mean $c' = -1.35$), or a conservative one (reporting S1's presence only for relatively strong internal responses; mean $c' = 0.66$).[5] In other words, in order to have an impact on the motor system, S1 must (1) be present and (2) be reported as being present. This is to say that the motor system's response depends on the *perceptual state* of the observer but only insofar as a stimulus is actually presented.

The present finding is incompatible with previous studies indicating that stimulus attributes relevant to action may be processed up to the level of response control, but remain unavailable for conscious report (Klotz & Neumann, 1999; Taylor & McCloskey, 1990; Vorberg et al., 2003). Within the present experimental format, such a claim would have been supported by S1 influencing the motor response *regardless* of whether the subjects were or were not able to report it. In other words, one would have expected a t_R dependency on d′ (hence on stimulus strength) for hits *and* misses. The finding that t_R for misses does not differ from trials in which S1 is absent (false alarms—FAs; correct rejections—CRs), implies that the sensorimotor response is essentially driven by the perceptual system and/or that its triggering threshold is higher than the presently assessed perceptual response criteria. In favour of this conjecture is the obser-

---

[4] Since the observers' ROC functions were asymmetrical, indicating that the noise-alone and the noise-plus-signal distributions of the internal responses had different variances (a typical case with visual signal detection tasks; Green & Swets, 1966), we computed the so-called d_e', hereafter noted d′. This sensitivity index is corrected for the difference in variance (see Green & Swets, 1966).

[5] The standard, relative criterion location on the sensory continuum axis, c, was computed as $c' = c/d'$, because c′ is not affected by unequal noise and signal-plus-noise variances (see Macmillan & Creelman, 1991).

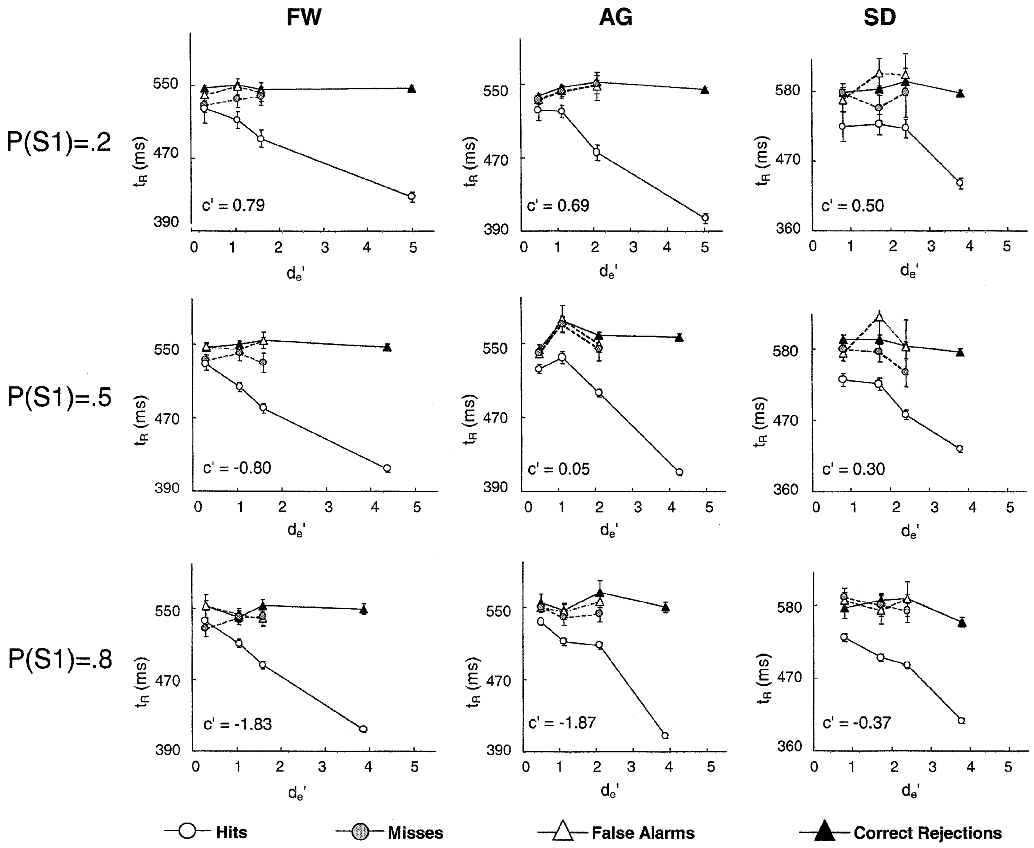

Figure 2. Experiment 1. Time points of reaction (t_R; see text) as a function of the d_e' to the masked stimulus (S1) for three observers (different columns), three probabilities of S1 occurrence (given as entries to each of the three panel rows), and the four SDT response categories (hits, misses, false alarms, correct rejections; see bottom inset). Mean c′-values (see footnote 5) are given for each observer and each S1 occurrence probability. Error bars indicate 95% confidence intervals.

vation that, in misses trials, t_R is insensitive even to S1 contrasts yielding d′s as high as 2 (where the average error rate was only about 13%). Hence, although stimulus energy was sufficient to permit a high detection performance, S1 did not affect the motor system without being ‘‘consciously’’ perceived.[6]

Figure 3 shows t_{S2}–t_R (open symbols) and t_{S1}–t_R (solid symbols) correlations as a function of the sensitivity to S1 (d′), for the three observers (different symbols) and the four SDT response categories (different panels). First of all, the figure demonstrates that, when S1 is absent (panels c and d), the t_{S2}–t_R correlation is rather strong (an average of about .7), and does not depend on either d′ or the response category (CR and FA in panels c and d, respectively).[7] More importantly, when S1 is present (hits and misses in panels a and b, respectively), the pattern of results strongly depends on the state of the observers' perceptual system. For misses, r_{tS2-tR} is high and constant across the different d′ levels (as for CR and FA), whereas r_{tS1-tR} is practically zero. This indicates that, as long as the observer does not ‘‘consciously’’ perceive S1 (see footnote 6), the latter does not affect the performance of the motor system even at high d′ levels (i.e., it does not account for any part of the motor response variance). For hits, in contrast (Figure 3a), the t_{S1}–t_R correlation increases with d′ from practically 0, at a d′ of about 0.5, to almost 0.7, at a d′ around 4. This 0.7 correlation index is practically the same as the one observed between t_{S2} and t_R in the absence of S1. This suggests that at d′s above 4, the motor response is entirely under the control of S1.[8] As expected, the t_{S2}–t_R correlation displays the almost mirror image of the t_{S1}–t_R correlation (as a function of d′): It starts at an

---

[6] In the following we will often refer to stimuli that exceed the subject's response criterion (and which are, thus, reported as being present) as being ‘‘consciously perceived’’. We are aware that this equation between consciousness and the strength of the internal response relative to the response criterion appeals to the somewhat contentious ‘‘subjective threshold’’ definition of consciousness (Cheesman & Merikle, 1984). This definition has been questioned chiefly because Signal Detection Theory (Green & Swets, 1966) suggests that participants may actually be phenomenally aware of the stimuli, but impose a decision criterion such that only sufficiently strong perceptions are endorsed as veridical. As such, subjective threshold effects may reflect below-criterion but nonetheless phenomenally weak conscious stimuli. The present experiments bypass this unsolved debate insofar as they are specifically aimed at assessing the relationship between the overt motor response and the internal state of the perceptual system (relative to the perceptual response criterion as defined within the SDT framework) evoked by *close to threshold stimuli* (d′ > 0!), rather than the undefined phenomenological state of the observer. While we do speculate on the relationship between (perceptual) response criterion and the conscious/nonconscious state of the observer, our speculations are certainly not less warranted than those presented in most of the previous related studies where the observer's phenomenological state remained undefined.

[7] Note that r^2_{xy} indicates the amount of variance of x that is explained by y, with the remaining variance being due to other factors, such as, in the present experiments, the pure motor variance, and the S1-onset variance (when present).

[8] It should be reminded that these high d′s where obtained under conditions where observers always detected S1 (S1 contrast was maximal) and could be computed only because observers pressed the wrong button by mistake (see footnote 2).

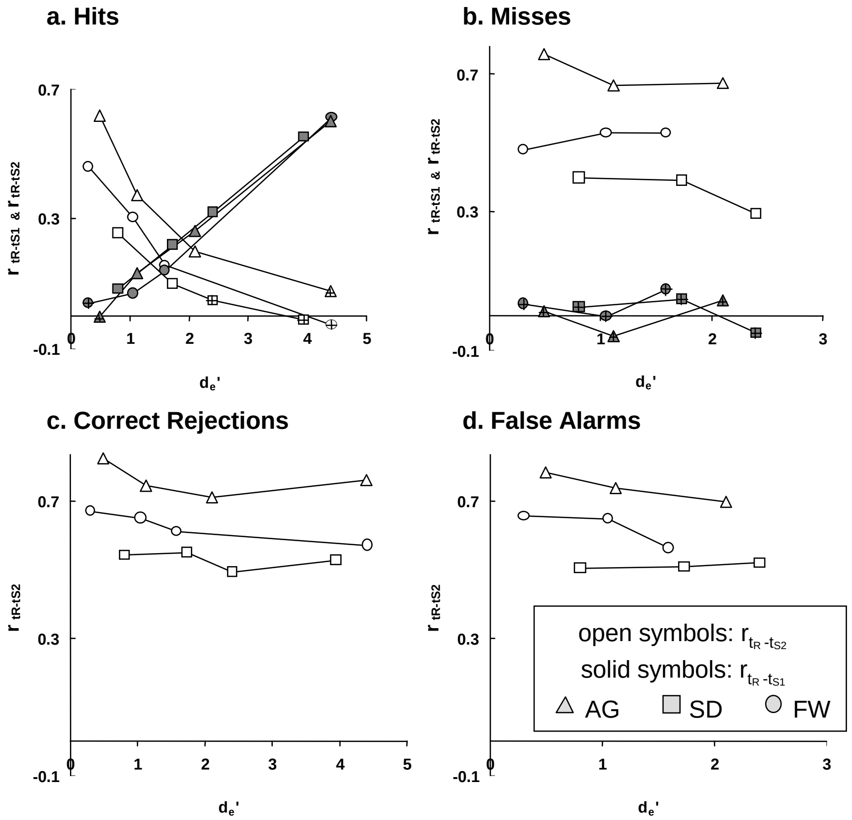

Figure 3. Spearman rank correlations between t_{S1} and t_R (r_{tS1-tR}, solid symbols) and t_{S2} and t_R (r_{tS1-tR}, open symbols) as a function of S1 d_e'. Different panels are for a different SDT response category (insets) and different symbols for different observers (FW: Circles; AG: Triangles; SD: Squares). Symbols *not* marked with a cross indicate correlations significant at or beyond $p < .01$.

average of about 0.6, for a d′ of 0.5, and decreases to practically 0, for a d′ above 4. Taken together, the two sets of functions displayed in Figure 3(a) show how the control of the motor response changes hands from S2 to S1, as this latter's strength (d′) increases. It suggests that the correlation of t_{S1} and t_R directly reflects the S1's capacity to trigger the motor response. Had S1 affected the motor response merely by means of the enhancement of S2 due to its summation with S1, or by means of drawing attention to the location where S2 appears, t_R should not have correlated with t_{S1}.

Experiment 2

The results of Experiment 1 are not compatible with the view that stimulus attributes are or may be processed up to the level of response control while remaining unavailable for conscious report (Klotz & Neumann, 1999; Taylor &

McCloskey, 1990; Vorberg et al., 2003). Rather, they suggest that, under the given experimental conditions, stimulus processing is strictly serial, with the sensory-perceptual system serving as a gate for the motor system. The contradiction between the present data and previous studies becomes then of focal interest. In the more recent studies yielding results contrary to the present ones, subjects had to perform a *choice* RT task and to *recognize* the prime with a 2AFC procedure (Klotz & Neumann, 1999; Vorberg et al., 2003). In contrast, our subjects were asked to perform a *simple* RT task and to *detect* the prime in a yes/no paradigm. It may then be that consciously *not* perceived stimuli affect the motor response only if the stimulus information on which the requested response bears matches one way or another the demands inherent in the programming of a reflex action (see Michaels & Stins, 1997). In Klotz and Neumann's (1999) and Vorberg et al.'s (2003) experiments, for example, the stimuli could have ''afforded'' a reflex action due to a high S–R compatibility. At odds with this interpretation, studies by Fehrer and Raab (1962) and by Taylor and McCloskey (1990) demonstrated that simple (as opposed to choice) reactions to a mask stimulus may also be speeded up by undetected primes. Thus, the task presently used cannot account by itself for the discrepancy between the present and past results.

Another difference between the present and past studies relates to the contrast of the masked stimuli: In Experiment 1 the highest contrasts for which a d' could be measured did not exceed 14% and 26% (for observers AG and FW, respectively). In contrast, all the studies cited above used 100% contrast stimuli whose ''invisibility'' was ensured by strong backward masking. In the present study, the duration and contrast (hence the energy) of the mask (S2) and masking (S1) stimuli were chosen so that S1 sensitivity follows a monotonic (''Type A'') masking function of SOA (Breitmeyer, 1984). Experiment 1 operated within the long SOA masking range chosen to ensure an almost flat masking function. Accordingly, the low visibility of S1 was not determined by the backward masking alone, but also by the weak physical energy of S1. It is thus possible that the presently assessed absence of a motor response to the ''missed'' masked stimuli is due to their low physical energy.

To test this hypothesis, Experiment 2 replicated Experiment 1 but involved a fixed and much shorter S1–S2 SOA (48 ms instead of the 162 ms average in Experiment 1). Since backward masking was much stronger at this short SOA, S1 had to be presented with a higher physical energy in order to yield the same detection d's as in Experiment 1. The 48 ms SOA was obtained by always presenting S1 and S2 at T_{108} and T_{156}, respectively (i.e., 108 ms and 156 ms after the reference time T_0).[9] S1 was always presented with a probability of .5.

---

[9] In Experiment 2, t_{S1} and t_{S2} were not jittered in time because of the reduced SOA range within which masking was sufficiently strong (for the purpose of this experiment). Since restrictions on the time range of these two variables proportionally corrupt the significance of their correlation with the response time (t_R), the correlation analysis introduced in Experiment 1 was abandoned in Experiment 2.

Except for these two differences, Experiments 1 and 2 were strictly identical. Only the two authors participated in Experiment 2.

Figure 4 shows the mean time points of the two observers' motor reaction (t_R) as a function of the sensitivity, d′, to S1. Overall, t_R–s are shorter for trials in which S1 is present (open and solid circles for hits and misses). For observer FW, this is true for all d′s and regardless of whether the observer indicated S1 to be present (hits) or not (misses). For observer AG, the pattern of results changes

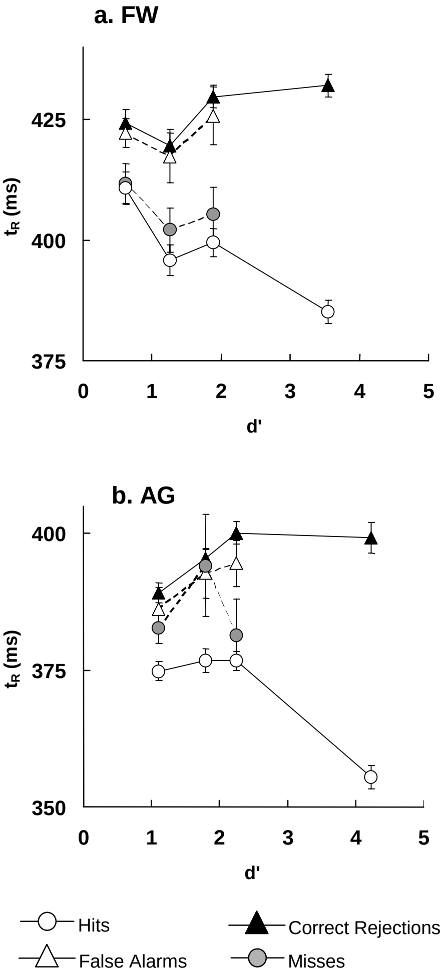

Figure 4. Experiment 2. Time points of reaction (t_R) as a function of the d′ to the masked stimulus (S1) for two observers (panel a: FW, panel b: AG), and the four SDT response categories (hits, misses, false alarms, correct rejections; see bottom inset). S1 probability occurrence was .5. Error bars indicate 95% confidence intervals.

with d′. For the two lower d′s (i.e., 1.1 and 1.8)[10] the overall t_R pattern resembles the one found in Experiment 1: t_R–s for FA, misses and CR group together around 390 ms while those for hits yield an average of about 375 ms. At the highest d′ (2.3), however, AG behaves like FW in that his t_R–s are comparably shorter for hits *and* misses.

The results of Experiment 2 are in line with the hypothesis that a masked stimulus may affect the motor system without being ‘‘consciously’’ perceived only if its physical energy is sufficiently high. The shorter t_R–s obtained for hits and misses (compared to those for FA and CR) suggest that the impact of the masked stimulus on the motor system does not strictly depend on the state of the observer’s perceptual system, i.e., that the stimulus does not need to exceed the perceptual criterion in order to influence the motor response. This is true for both observers with a more restricted d′ range for observer AG, that is only for d′s equal to and higher than 2.3 (obtained with S1 contrasts of about 0.3). Figure 5 shows for both observers the contrasts with which S1 was presented in Experiments 1 and 2. The figure demonstrates that, for observer FW, these contrasts differed sharply between the two experiments. For observer AG, in contrast, the increase in contrast between Experiment 1 and 2 was comparatively

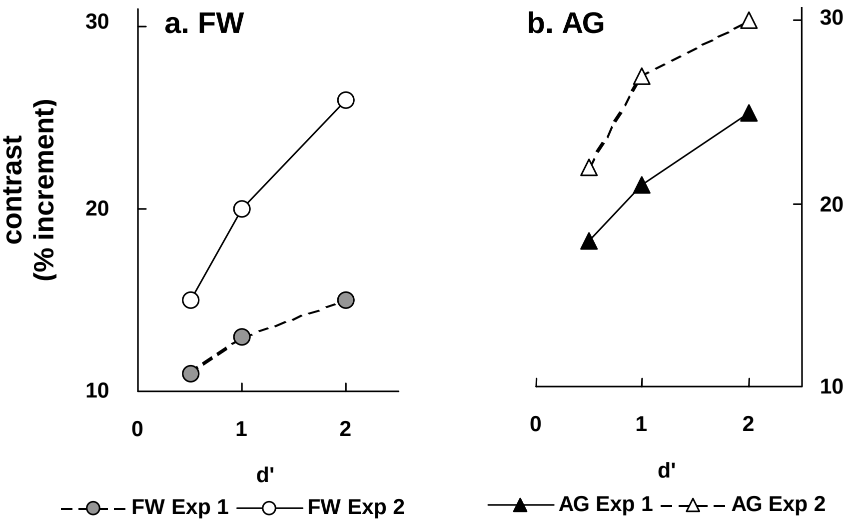

Figure 5. Mean masked stimulus (S1) contrasts (increments with respect to the 47 cd/m^2 grey background) used in Experiments 1 and 2 (solid and open symbols, respectively) to yield average d′s of about 0.5, 1, and 2 for observers FW (panel a) and AG (panel b).

---

[10] The difference between the d′s decided a priori (0.5, 1, and 2) and the d′s actually measured in the main experiments is most likely due to an improvement of the observers’ detection skills in the main, as compared to the preliminary experiment.

small with only the contrasts yielding the highest d′s differing markedly between experiments. Hence, the assumption that the physical energy of S1 has to exceed some critical value in order to be processed independently of the state of the perceptual system, accounts for the absence of an effect of the undetected stimuli (misses) on the motor response at the two lower d′ levels of observer AG.

GENERAL DISCUSSION

The present experiments revealed two types of effect that masked visual stimuli may have on the motor system. The results of Experiment 1 support the view that when backward masking is relatively weak (so that the physical energy of the masked stimulus at a given d′ is also weak), the impact of the masked stimulus on the motor system depends on whether or not its internal response exceeds the observer's perceptual response criterion. Experiment 2 showed that when the physical energy of the masked stimulus was significantly stronger than in Experiment 1 while yielding the same levels of visibility (as a consequence of using a shorter SOA and hence of stronger backward masking effects), the impact of the masked stimulus on the motor system was independent of the state of the observer's perceptual system.

Taken together the reported results are consistent with the notion of an implicit action system separate from an explicit perceptual system, whether these systems are sustained by two distinct feedforward pathways (Milner & Goodale, 1995; Ungerleider & Mishkin, 1982; see also Rossetti & Pisella, 2002), or by feedforward and recurrent processes (Enns & DiLollo, 2000; Lamme, 2001; Lamme & Roelfsema, 2000). On both accounts, however, the dichotomy between vision for perception and vision for action (as demonstrated by numerous experiments, a selection of which is mentioned in the introduction) is nowadays taken to imply that the implicit sensorimotor system is more susceptible to (or more efficient in the processing of) visual stimulation than the explicit perceptual system. Contrary to that intuition, the present experiments demonstrate that the conditions under which the motor response is independent of whether or not a visual stimulus is explicitly processed, are rather limited. In terms of the ''two visual systems hypothesis'', the present data suggest that as long as the physical stimulus energy is low, visual stimulation is exclusively processed along the explicit pathway. Under such conditions, the perceptual system serves as a gate for the motor system. Only stimuli that pass the gate are fed forward to the motor processing. Whether or not a stimulus passes the gate depends on the observer's perceptual criterion as described by Signal Detection Theory (Green & Swets, 1966). It is only when the physical stimulus energy is strong enough that the ''automatic pilot'' comes into play as triggered by the implicit, subcriterion (or ''nonconscious'') sensorimotor processing. Along this line of thought, Schlaghecken and Eimer (2002) have shown that primes which are incompatible with the correct motor response give rise to response inhibition only if they exceed a hypothetical (high) threshold. Such high energy thresholds for reflex, nonconscious behaviour might be ecologically useful since they prevent humans from reacting to negligible and hence irrelevant stimulation.

Experiments 1 and 2 did not differ only with respect to the physical energy of the masked stimulus. Presenting S1 with different physical energies while keeping its visibility constant was achieved by presenting it within different SOA regions of the backward masking function. It cannot, therefore, be asserted with certainty that the different pattern of results obtained in the two experiments is exclusively due to the difference in physical energy of S1 with the different SOA ranges playing no role. It should be noted, however, that in Experiment 2 observer AG showed a t_R-effect for miss trials only for his highest d′. Hence, the shorter SOA (48 ms) per se could not be a determinant factor in ‘‘switching on’’ the automatic pilot since it did not entail such effects for the lower d′s. Rather, the physical energy of S1 must exceed some critical value in order for it to affect the motor response without being consciously perceived. Note that this critical energy revealed via an SOA manipulation could be confounded with the higher temporal summation index (between S1 and S2) inherent to the shorter SOA used in Experiment 2. Consequently, it is possible that, in Experiment 2, S1 affected the motor response merely by facilitation of the masking stimulus (i.e., by summing with S2), and not because it ‘‘triggered’’ the prepared motor response. In this context, it would be interesting to correlate tS1 and tR for such shorter SOAs. If at short SOAs S1 tends to summate with S2, one would expect to find only a small (if any) correlation between t_{S1} and t_R (but see footnote 9). Evidently, this result would further undermine the alleged ability of masked stimuli to ‘‘trigger’’ motor responses.

The absence in both experiments of any S1 effects on the motor response for FA trials indicates that perceptual noise does not bear on the motor system even when the perceptual internal response exceeds the observer’s perceptual criterion. This suggests that the modus operandi of the two threshold systems differ fundamentally. We propose that the perceptual system can be regarded as a decisional system described by standard SDT, whereas the sensorimotor system behaves more like a reflex system the characteristics of which are at odds with SDT but in accordance with High Threshold Theory (HTT; see Macmillan & Creelman, 1991) where noise cannot hurdle the threshold so that response errors on noise trials arise from guessing only.

Overall, the present experiments demonstrate conclusively that the conditions under which a sensorimotor response triggered by visual stimulation is independent from the conscious detection of the stimulation are limited. We showed that implicit sensorimotor processing of visual stimulation is by no means more ‘‘efficient’’ than explicit perceptual processing. Our experiments rather suggest that implicit sensorimotor behaviour depends on stimulus energy exceeding a relatively high threshold specific to this kind of motor response. Given the multitude of studies demonstrating the efficiency of the ‘‘automatic motor pilot’’, these results come as a surprise.

REFERENCES

Aglioti, S., DeSouza, J. F. X., & Goodale, M. A. (1995). Size-contrast illusions deceive the eye but not the hand. *Current Biology*, *5*, 679–685.

Breitmeyer, B. (1984). *Visual masking: An integrative approach*. Oxford, UK: Oxford University Press.

Bridgeman, B., Kirch, M., & Sperling, A. (1981). Segregation of cognitive and motor aspects of visual function using induced motion. *Perception and Psychophysics*, *29*, 336–342.

Bridgeman, B., Lewis, S., Heit, G., & Nagle, M. (1979). Relation between cognitive and motor-oriented systems of visual position perception. *Journal of Experimental Psychology: Human Perception and Performance*, *5*, 692–700.

Cheesman, J., & Merikle., P. M. (1984). Priming with and without awareness. *Perception and Psychophysics*, *36*, 387–395.

Desmurget, M., Prablanc, C., Rossetti, Y., & Arzi, M. (1995). Postural and synergic control for three-dimensional movements of reaching and grasping. *Journal of Neurophysiology*, *74*, 905–910.

Enns, J. T., & DiLollo, V. (2000). What’s new in visual masking? *Trends in Cognitive Sciences*, *4*, 345–352.

Fehrer, E., & Raab, D. (1962). Reaction time to stimuli masked by metacontrast. *Journal of Experimental Psychology*, *63*, 143–147.

Gentilucci, M., Chieffi, S., Daprati, E., Saetti, M. C., & Toni, I. (1996). Visual illusion and action. *Neuropsychologia*, *34*, 369–376.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.

Klotz, W., & Neumann, O. (1999). Motor activation without conscious discrimination in metacontrast masking. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 976–992.

Lamme, V. A. F. (2001). Blindsight: The role of feedforward and feedback corticocortical connections. *Acta Psychologica*, *107*, 209–228.

Lamme, V. A. F., & Roelfsema, P. R. (2000). The distinct modes of vision offered by feedforward and recurrent processing. *Trends in Neurosciences*, *23*, 571–579.

Macmillan, N. A., & Creelman, C. D. (1991). *Detection theory: A user’s guide*. New York: Cambridge University Press.

Michaels, C. F., & Stins, J. F. (1997). An ecological approach to stimulus–response compatibility. In B. Hommel & W. Prinz (Eds.), *Theoretical issues in stimulus–response compatibility* (pp. 333–360). Amsterdam: Elsevier.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford, UK: Oxford University Press.

Ogmen, H., Breitmeyer, B., & Melvin, R. (2003). The what and where in visual masking. *Vision Research*, *43*, 1337–1350.

Rossetti, Y., & Pisella, L. (2002). Several ‘‘vision for action’’ systems: A guide to dissociating and integrating dorsal and ventral functions. In W. Prinz & B. Hommel (Eds.), *Attention and performance XIX: Common mechanisms in perception and action* (pp. 62–119). Oxford, UK: Oxford University Press.

Schlaghecken, F., & Eimer, M. (2002). Motor activation with and without inhibition: Evidence for a threshold mechanism in motor control. *Perception and Psychophysics*, *64*, 148–62.

Taylor, J. L., & McCloskey, D. I. (1990). Triggering of preprogrammed movements as reactions to masked stimuli. *Journal of Neurophysiology*, *63*, 439–446.

Ungerleider, L., & Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), *Analysis of motor behavior* (pp. 549–586). Cambridge, MA: MIT Press.

Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2003). Different time courses for visual perception and action priming. *Proceedings of the National Academy of Science*, *100*, 6275–6280.

Weiskrantz, L. (1986). *Blindsight: A case study and implications*. Oxford, UK: Oxford University Press.

Original manuscript received October 2003
Revised manuscript received February 2004