Modification of a functional motor task by non-consciously perceived sensory stimuli

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In recent years it has been suggested that processing of visual information is divided between a ventral stream, responsible for object recognition and conscious processing of object properties, and a dorsal stream mediating automatic integration of visual information into a motor task. We used metacontrast masking to prevent conscious perception of visual cues concerning the load of an object to be lifted in a precision grip. It was found that when such non-consciously perceived cues warned of a load change, they allowed the subjects to produce the grip force profile appropriate to the new load. It is concluded that non-consciously perceived visual information can be utilised to adapt a functional motor task to actual conditions. *NeuroReport* 13:637–640 © 2002 Lippincott Williams & Wilkins.

Key words: Direct parameter specification; Dorsal stream; Metacontrast masking; Precision grip; Sensorimotor; Ventral stream; Visuomotor

INTRODUCTION

Information from the visual cortex is processed via two pathways: a ventral path over the inferotemporal cortex and a dorsal path leading eventually to the posterior parietal cortex. It has been suggested that the more direct and phylogenetically more recent ventral stream is responsible for object recognition and conscious processing of object properties, while the older dorsal stream mediates automatic integration of visual information into a motor task [1]. This idea arose from findings that lesions of the ventral stream lead to a failure to consciously recognise or describe objects, but spare the ability to integrate visual information into ongoing motor tasks, such as grasping an object [2]. Such lesions are rare, but an experimental dichotomy can be created between conscious object perception and object manipulation in intact man. This uses the phenomenon of metacontrast masking (for review see [3]): a visual stimulus followed after a short interval (e.g. 50 ms) by a similar but larger stimulus is not consciously perceived. However if the smaller stimulus provides information in a simple choice reaction task, reaction times are shortened although the stimulus is completely masked [4,5]. These results have demonstrated that masked visual information can affect motor activation. It remains unclear, however, if masked visual information can qualitatively modify motor performance, that is, if masked visual information can be used in motor selection. In order to test this possibility we have combined metacontrast masking with performance of a natural motor task, the lifting of an object in a precision grip, which requires elements of predicted grip forces based on object characteristics and adaptation based on sensory information obtained during a lift.

MATERIALS AND METHODS

Fifteen neurologically normal subjects were recruited for the study (10 male, five female; aged 20–49 (median 23) years). All subjects were assessed as right-handed using the modified Edinburgh handedness protocol [6]. All had normal or corrected to normal vision. They received a payment of DM 20 for participating and were informed that they could also receive up to DM 30 extra, dependent on their performance in the section 2 (see below) of the protocol: DM 0.50 was deducted for each lifting trial in which the dynamic phase of the grip force curve was not suitable for the load information presented before each trial. The subjects gave their informed consent to all procedures, which had been approved by the local ethics committee.

Each experiment lasted 1–2 h, depending on the number of pauses requested by the subject, and was divided into three phases. The first, uncued lifting, was designed to give the subject practice in lifting the object in its light or loaded state and to optimise their grip force levels for each load. For details of this protocol and of the apparatus itself see [7]. This section also provided a measure of the overshoot in grip force seen when a light load was unexpectedly encountered following a lift of the heavy load relative to the level used when a light load was expected (see Fig. 1). No information was provided about object loading: thus it is to be expected that the subjects lifted the object with the assumption that its load remained unchanged from the last lift [8]. In the second section, cued lifting, the subjects were provided with visual cues on a computer screen concerning the load of the object in the next trial. This information was sometimes false, but subjects were strictly instructed to regard it as true and to apply grip force accordingly. This visual information was a modified form of the system developed by Klotz and Neumann [5]. The subject fixated on a point at the centre of the screen. In each trial two pairs of horizontally aligned geometric forms were presented for 30 ms each. The first pair contained the information about object load in the next trial, with a diamond left and a square right indicating the light load, while the reverse indicated a heavy load (Fig. 2a). The second pair consisted of two diamonds, which overlay and completely enclosed the first pair. This was the subject's signal to lift the object. Delay between appearance of the pairs (Fig. 2b) was either 660 ms, in which case the subject was consciously aware of the load cue, or 45 ms, in which case the load cue was masked. A sequence of 60 trials was presented, yielding 15 trials where a light load was encountered following a heavy load in the previous trial. These 15 trials fell into 3 groups of five trials: (1) visible load cue, light signalled and encountered; (2) visible load cue, heavy signalled but light encountered; (3) masked load cue, light signalled and encountered. In five further trials the possibility of a stereotyped response to a masked stimulus was tested (masked load cue, heavy signalled and encountered). The third section, reporting, tested that the subjects were truly unable to consciously describe the masked information. The subjects saw the same sequence but were now required to indicate on a keyboard if the load cue signalled a light or a heavy load. In cases of uncertainty they were instructed, as was the case in the second section, to choose intuitively. The rate of correct responses to masked stimuli varied between 43 and 77% (median 53%). No correlation was observable between this score and the degree of success in correcting the overshoot in section 2, using either parametric (−0.337, $p = 0.267$) or non-parametic (Spearman rank rho −0.078, $p = 0.7864$) methods. The precentage scores for the masked cues were then processed using the Clopper-Pearson method to yield the 95% confidence interval for the binomial parameter (PI). A lower limit above 50% was taken as an exclusion criterium. Two subjects were eliminated on this basis. The other subjects did not achieve scores above levels expected by chance and were thus unable to consciously perceive the masked stimuli [5].

RESULTS

In the uncued condition all subjects showed a significant modulation of grip force according to object load (Kruskal-Wallis rank test, 12 subjects $p < 0.001$; one subject $p < 0.05$). When a light load was unexpectedly encountered following

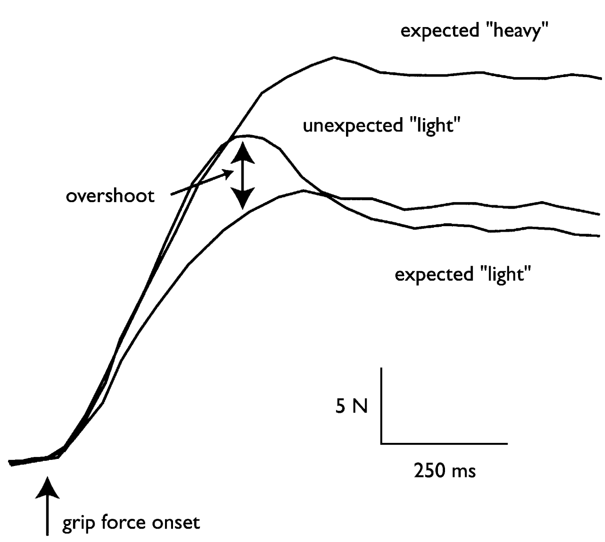

Fig. 1. Grip force curves generated by a representative normal subject while lifting the object without visual cues under three conditions. The lower curve shows the grip force profile utilised for a light load when the subject had encountered this load in the previous trial, while the upper curve shows that utilised for a heavy load when the subject had encountered this load in the previous trial. The third profile is that for a trial in which the light load was encountered, but the last load had been heavy. It may be seen that the force profile follows that used for the heavy object before sensory cues about the true load allow correction to a suitable level of force. The delay involved in this correction results in a characteristic overshoot in the grip force curve.

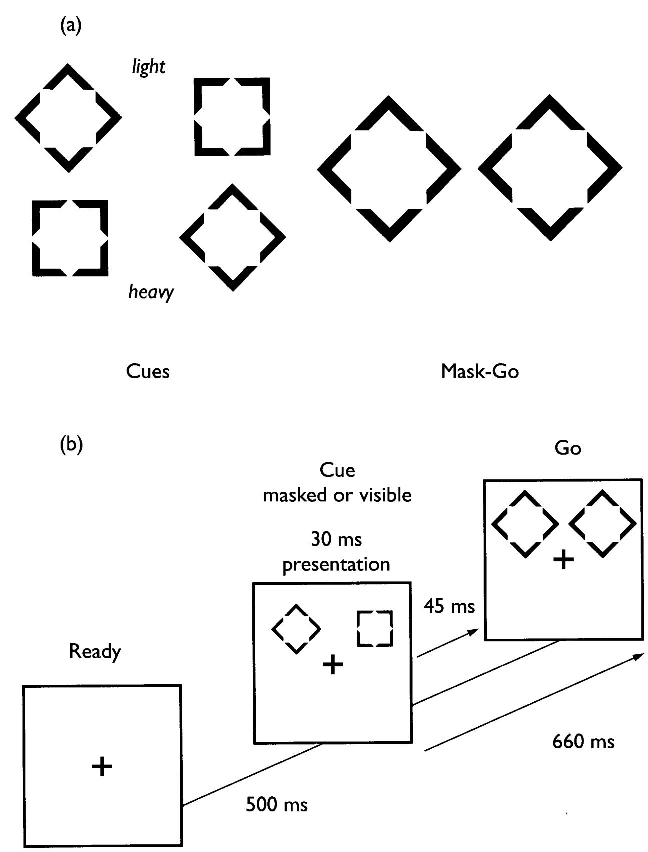

Fig. 2. (**a**) the geometric forms used as warning cues (left) and as the masking/go signal (right) in the cued lifting section; (**b**) the protocol used to selectively mask the warning cues.

a lift of the heavy load in the uncued condition, subjects developed significantly greater peak grip force than that used when a light load was expected (Wilcoxon signed rank test, $p < 0.01$). This represented a mean ($\pm$ s.e.m.) overshoot of $21 \pm 6\%$, $n = 13$). Figure 3 illustrates this finding, along with the corresponding findings for the three cued conditions, expressed as a percentage of the peak grip force achieved in the uncued light condition. It may be seen that when the subjects were falsely informed by a visible cue that the load would remain unchanged from the last trial (heavy), a clear overshoot in peak grip force was apparent ($p < 0.05$, non-parametric one sample sign test). If, however, a cue, whether visible or masked, indicated correctly that object load would change from heavy to light, grip force values were comparable with those seen in the uncued light condition (visible mean overshoot $6 \pm 5\%$; masked mean overshoot $1 \pm 5\%$). That is to say, the warning cues were successful in preventing overshoot (control *vs* warning $p =$ NS, non-parametric one-sample sign test). That this was not due to the subjects adopting a grip force appropriate to the light load whenever the cue was masked is shown in the final column of Fig. 3: here the subjects were cued, correctly, that the load would remain heavy. It may be seen that a significantly higher grip force, appropriate for the heavy load, was achieved ($p < 0.001$, non-parametric one-sample sign test). Thus it has been demonstrated, to our knowledge for the first time, that non-consciously perceived visual information can be used to optimise grip force parameters in a functional motor task.

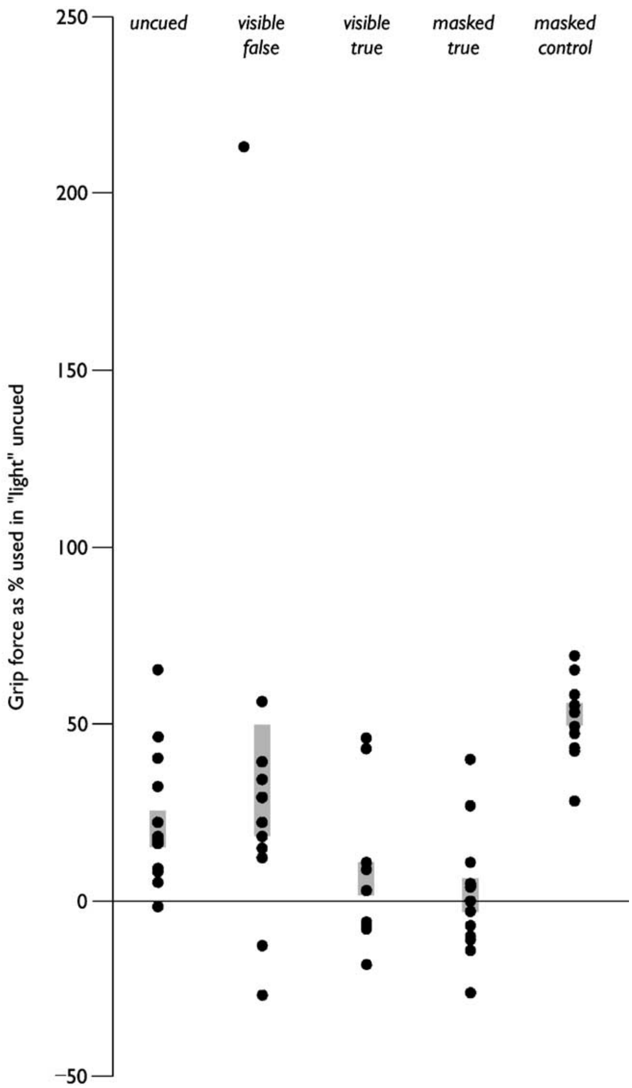

Fig. 3. Peak grip force used by the individual subjects under four conditions, expressed as a percentage change from the grip force generated to lift the light load in the uncued section. The grey boxes represent the standard error on either side of the group means. Unexpectedly encountering a light load led to a significant overshoot in the grip force curve ($p < 0.05$, non-parametric one sample sign test, uncued and visible false). A cue, visible or masked, warning of load change, prevented this overshoot (control *vs* warning $p =$ NS, non-parametric one sample sign test). The final column shows the grip force used when a masked cue indicated that load would remain heavy. This led to the significantly higher forces required for the heavy load ($p < 0.001$, non-parametric one-sample sign test).

DISCUSSION

Previous studies have demonstrated that masked visual information can be used to speed (or slow) simple reaction time tasks [4,5]. In these cases the cues were largely spatial in nature, indicating the hand with which the subjects should react. As such the findings of these studies could be held to be compatible with the idea that the dorsal stream is a where system, concerned with spatial vision, while the ventral system deals with what, that is to say, object identity [9]. Such a model is simplistic, and it has been suggested by Goodale [10] that the role of the dorsal system is to integrate visual information concerning object properties, such as size and orientation directly into motor programs concerned with object manipulation. The present results show that non-consciously perceived visual cues of a highly abstract nature can be used to select the optimal parameters in a functional manipulative motor task. There exist at least two explanations for these findings. Firstly the dorsal system could be capable of form recognition and have access to memory responsible for mapping the representation of the concepts light and heavy on to the motor program responsible for lifting the object. If this is the case, then the dorsal system cannot be seen as purely sensorimotor in nature, but must be involved, albeit at a sub-conscious level, in cognitive processing. A second explanation, however, would be that the ventral pathway is capable of object recognition below the level of conscious awareness and that this information has access to the motor program responsible for lifting the object. This idea is supported by the results of single cell recording in the inferotemporal cortex of awake macaque monkeys reacting to masked visual stimuli [11]. In the absence of a mask, or when the mask followed the stimulus by > 60–70 ms (that is, at an interval at which conscious perception begins to function in man), the cells fired for 200–300 ms post-stimulus. Shorter masking intervals caused a progressive decrease in response duration and firing rate. This was associated with a sharp decrease in the information coded by this activity. It remained the case, however, that considerable information was coded in the first 50 ms of the response. If this situation is applicable to man, this information could form the basis for modification of a motor program via the ventral system without conscious awareness of the stimulus. Temporal lobe lesions in monkeys do not appear to produce disruption of reaching movements [12], which would indicate that the dorsal system must play an essential role in actual lifting of the object. Which of these alternatives is the case remains, therefore, uncertain: it may be possible to clarify the situation further by using techniques such as transcranial magnetic stimulation for short-term disruption of the dorsal stream or imaging studies using fMRI. Whatever the underlying neurophysiology, it is apparent that the utilisation of masked visual information in adapting functional motor tasks provides a useful tool for investigating the role of conscious perception in a variety of behaviour and in motor disorders such as, for example, Parkinson's disease, where conscious and reflex motor acts are differentially affected [7].

CONCLUSION

This study has shown that subconsciously perceived visual information can be utilised to adapt a functional motor task to actual conditions. This adaptation clearly involved cognitive processes, indicating, in contradiction of current theory, that either the dorsal visual system is capable of object recognition and parameter selection, or that the ventral system can access sensorimotor processing at a subconscious level.

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