studied in this context, participants compare multiple elements of the display. For instance, the Titchener circles illusion is commonly assessed by asking participants to compare the sizes of the two central disks. Nearly all action tasks in these studies, however, involve a two-finger pincer grip, which is mediated by the size of only one element of the display. While the judgment versus reaching difference between these two tasks has been highlighted, this "one versus two elements" difference provides an alternative explanation for the observed effects.

We have repeatedly found that if judgments are based on a single element, the effects of pictorial illusions are greatly reduced, often to the same levels observed with reaching behaviors. Conversely, in some situations, we have found that when actions are simultaneously based on multiple elements of a display, actions are more strongly influenced by pictorial illusions (Fig. 1). Whereas the studies related to this approach cited by Glover used only two-dimensional stimuli (Vishton et al. 1999), leaving the findings open to the interpretation that they were specific to "pantomime" reaches, we have more recently extended these results to reaches for three-dimensional targets as well (Vishton & Fabre 2003; Vishton et al., submitted). These effects are not present at the very conclusion of the reaching action, when the size of the target object determines the size of the grasp, but the effects are apparent well past the midpoint of the reach. This work has also suggested that the familiarity of a task plays an important role in determining the effects of an illusion. For most people, reaching is a far more common, familiar task than overt judgment.

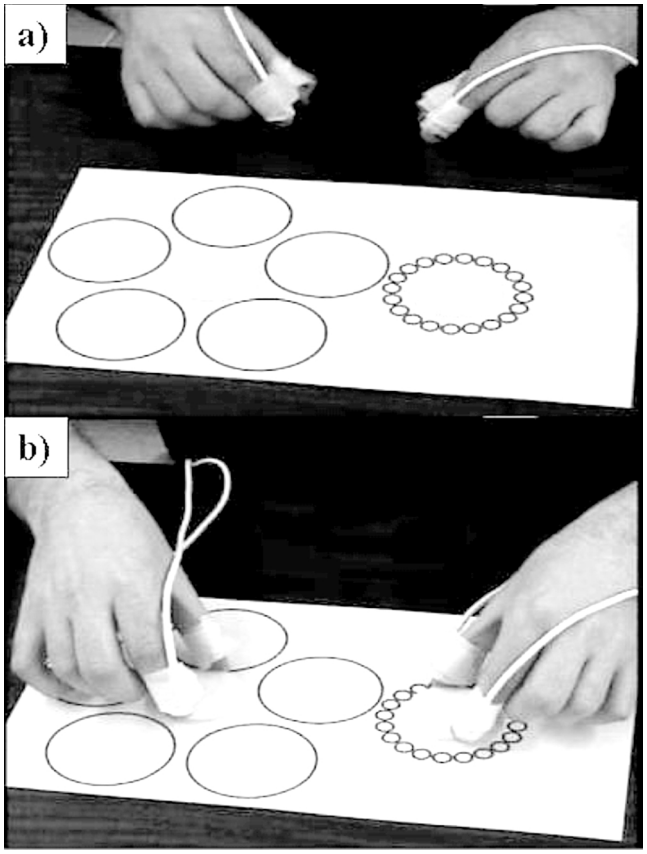


Figure 1 (Vishton). The start (a) and end (b) of a reach mediated by sizes of two target elements. The grip-scaling component of one-handed, pincer grip reaching is largely immune to the effects of the Titchener circles illusion, but, if a two-handed reach is made, based simultaneously on both central disks in the display, the effects are significantly larger. For both "perception" and "action," it thus seems that illusions are small when based on a single element of a display and large when based on multiple elements.

This account is not directly at odds with the PVC model, per se. My claim here is that there are facets of the interaction between response task and illusion magnitude that are better explained by alternative approaches. The PVC distinction may be present, but other important factors must be included in any complete understanding of how visually registered information leads to precise action choice, planning, and implementation.

Glover's focus on how different phases of an action are influenced by different sources of information (e.g., contextual vs. spatial information) is quite consistent with our approach, advancing it to a much more precise level. As Glover clearly points out, the choice of an action plan is mediated by different information than the control of the action once the general action plan has been set. We should therefore expect the distribution of visual attention to be different at these two moments. Differences such as these may influence how pictorial illusion displays are processed, whether separate visual processing streams are involved or not.

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Planning, control, and the illusion of explanation

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Abstract: Several aspects of Glover's planning–control model (PCM) appear incompatible with existing data. Moreover, there is no logical reason to suppose that separate visual representations should be required for the "planning" and "control" of actions in the first place. Although intuitively appealing, the PCM appears to lack strong empirical support.

No need for separate representations. It seems clear that different types of information are relevant for regulating different aspects of an action. However, it is not clear why separate visual representations of the same object feature (e.g., size) should be necessary for the initial programming and the on-line control of the same aspect of the action (e.g., grip aperture). On-line control requires a representation of the desired state of the effector (e.g., the desired grip aperture), a representation of the current state of the effector (e.g., the moment-to-moment size of the grip), a comparator, and a means by which to influence the effector. Of these components, visual information about the target object can be used to update only the desired state of the effector. Once an action has been initiated, however, no new sources of visual information about the target become available. Even if the target were to change in some way during the action (e.g., increase or decrease in size), the computations necessary to derive the size of the object are not any different than if the object were to change size before the action was initiated. That is, the precise (and absolute) metrics of the target object can be computed in the same way before and during the action. Why, then, would it not be advantageous for the motor system to make use of the same computations (or, the same "visual representation," in Glover's parlance) for movement programming and on-line control?

Nonspatial object features. Glover proposes that a putative action planning system "is responsible . . . for all movement parameters relating to nonspatial target characteristics" (sect. 1.1.2, para. 4). According to Table 1 in the target article, the specification of grasping and lifting forces should be the domain of the action planning system – a system that accesses a host of cognitive information about the object. One would suspect, then, that larger grasping and lifting forces should be observed when the actor picks up an object that is judged to be heavier (or larger) than an-

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other object. Contrary to this prediction, Flanagan and Beltzner (1999) showed that a perceptual size-weight illusion (in which a larger object is consistently judged to weigh less than an equally massive but smaller object) does not influence the scaling of grip and load forces when the target objects are lifted a few times. This was true for force measurements taken well before proprioceptive and haptic feedback loops could modulate the grasping forces – in other words, the measured forces must have been programmed well in advance of contact with the object. In a similar vein, Westwood et al. (2000b) showed that a pictorial size illusion affected the perceived size of target objects, but not the force with which the objects were grasped when they were lifted. Importantly, all of the objects in that experiment had the same mass. Clearly, cognitive judgments about object size and mass are not always taken into account when programming grasping forces.

Grasping remembered objects: A rapid transition in control. Glover suggests that a "control" representation of the target object gradually fades from memory when vision is taken away, leading to an increased influence of a "planning" representation for actions made to remembered objects. We have shown in several studies that the effects of pictorial illusions on action are exquisitely sensitive to the time at which vision of the target object is removed. In one recent study (Westwood & Goodale 2003) we show that a size-contrast illusion does not influence grip aperture when the target is visible during the reaction time interval, even if vision is removed at movement onset. However, the illusion reliably influenced grip aperture when vision was removed during the reaction time period (i.e., for the 250 msec between response cueing and movement onset). This finding is difficult to reconcile with a gradual transition from a "control" to a "planning" representation when vision of the target object is removed. The data are more consistent with a "real time" view of visuomotor programming in which retinal information about the target object is converted into a calibrated motor program at the time the action is actually required. Movement planning that takes place before this time likely accesses a visual representation of the target object that is laid down by the perceptual mechanisms in the ventral visual pathway (Goodale et al. 2004).

The "dynamic illusion effect": A methodological illusion? The key piece of evidence in favour of the PCM is the finding reported by Glover and Dixon (e.g., Glover & Dixon 2001a) that visual illusions have a greater influence on movement kinematics that occur earlier rather than later in the movement. Glover uses a *scaled illusion effect* to demonstrate this phenomenon. The scaled illusion effect is simply a ratio of the illusion's absolute effect on a movement parameter (I) divided by the effect of a veridical change in an object's features on the same movement parameter (O); this measure is calculated for a number of temporal points throughout the movement duration. Glover argues that this ratio is necessary to take into account the fact that visual object features do not have a constant influence on movement kinematics during execution: For example, the slope of the psychophysical function relating object size and grip aperture increases monotonically throughout the course of a grasping movement. When scaled illusion effects are plotted as a function of relative movement duration, Glover reports a gradual decrease over the course of the movement. This is interpreted as evidence that a "control" system that is impervious to visual illusions corrects spatial errors introduced by a "planning" system that is quite sensitive to visual illusions. The problem with this type of analysis is that the same effect would be obtained even if the absolute effect of the illusion were to remain stable over time (or even increase slightly), because of the monotonically increasing term in the denominator of the ratio. In this case, one would surely not wish to conclude that an illusion effect was being corrected as the response unfolded! If the PCM is correct, one should be able to demonstrate statistically that the absolute illusion effect decreases over the duration of the action. Such proof has not been provided in many of Glover's key experiments. Moreover, at least one recent study has looked for but failed to find such statistical evidence (Danckert et al. 2002).

Summary. There is little empirical support for the notion that separate visual representations underlie the planning and control of manual actions. Indeed, there is no good theoretical reason to suppose that separate representations would be necessary in the first place.

Planning differences for chromaticity- and luminance-defined stimuli: A possible problem for Glover's planning–control model

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Abstract: We report data from an experiment using stimuli designed to differ in their availability for processing by the dorsal visual pathway, but which were equivalent in tasks mediated by the ventral pathway. When movements are made to these stimuli as targets, there are clear effects early in the movement. These effects appear at odds with the planning–control model of Glover.

The interpretation of the ventral and dorsal visual processing streams (first identified by Ungerleider & Mishkin [1982]) as "what" and "how" systems, respectively (Milner & Goodale 1995), marked a turning point in understanding the functional role of this anatomical distinction. In his target article, Glover provides a compelling summary of the evidence supporting the planning–control model. By suggesting that initial planning and current control are functions of different parts of the parietal cortex, Glover's model gives substance to a distinction first introduced by Woodworth (1899). Equally important, this model marks another stage in our developing understanding of the ventral-dorsal distinction.

Our aim in this commentary is to describe data, recently collected using a new procedure (Wright et al., submitted), which appears inconsistent with the planning–control model. Our goal in this experiment was not to test the planning–control model. Instead, the objective was to assess the relative sensitivity to luminance- versus chromaticity-defined targets of "how" tasks, in which the goal is to produce a movement to an object, and "what" tasks, in which the goal is to perceive some aspect of an object.

The impetus for this experiment was the what-how distinction (Milner & Goodale 1995) and a long line of evidence suggesting reduced color sensitivity in the dorsal stream. Although the evidence is far from clear-cut, it appears that the dorsal visual stream receives direct inputs from only the magnocellular pathway. In contrast, the ventral stream appears to receive projections directly from both pathways. Livingstone and Hubel (1988) have argued that these two channels differ physiologically in four major ways: color sensitivity, temporal resolution, contrast sensitivity, and acuity. Specifically, they suggest that the parvocellular system is highly color selective but the magnocellular system does not code color differences.

In one procedure of our experiment, subjects had to identify briefly presented, masked stimuli as one of four shapes. A given target was defined relative to the gray background by a difference either in luminance or in chromaticity. Luminance-defined targets had the same hue and saturation as the background, whereas saturation-defined targets were green and equiluminant with the background. Various luminances and saturations were used to define targets.[1] The results from this procedure identified levels of luminance and saturation that produced equivalent levels of performance in this identification ("what") task.

In a second procedure, matched gray and green stimuli were used to define targets for rapid, high-accuracy, three-dimensional pointing movements. Consistent with our expectations, movements to green targets took longer and had larger endpoint errors

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