

Editorial

Integrating perception and action through cognitive neuropsychology (broadly conceived)

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This special issue of *Cognitive Neuropsychology* aims at providing a forum for empirical and theoretical research on the integration of perceptual and motor processes in the human mind. The initiative originated at a workshop on "Integrative approaches to perception and action" (Trieste, 27 October, 2006), a satellite event to the 14th Kanizsa Lecture.¹ The 2006 lecture addressed the architecture of human vision from a broad perspective, reviewing a range of neuropsychological, imaging, and behavioural data to reveal the organization of visual pathways and relate it to the functions of vision. The satellite workshop presented alternative views and additional empirical findings, providing an exciting backdrop for the lecture. The number of valuable insights that ensued encouraged us to develop the project into a collection of printed papers. This special issue is the outcome of this process.

Historically, the cognitive sciences have used the adjective "integrative" in different ways. The

earliest dates back at least to the publication of Sherrington's classic, *The Integrative Action of the Nervous System* (Sherrington, 1906), which aimed at studying how separate organs and body parts are brought together into a unified, organized organism by the workings of the nervous system. The integrative phenomena that came under Sherrington's scrutiny were limited by his emphasis on reflexes as units of integration and by his corresponding interest in animal preparations displaying reflex behaviour (Levine, 2007). However, there is little doubt that understanding how different brain mechanisms relate to one another and to other bodily mechanisms, such as those mediating actions, remains central to contemporary cognitive science. A second sense refers to the need of integrating different levels of explanation when studying the mind/brain. Indeed, the idea that approaches limited to a single level of analysis do not suffice to unravel how the brain works forms the core dictum of integrative neuroscience

¹ For further information about the lectures, see <http://www.psico.units.it/convegni/kanlect/2006/index.php3>. A live recording of the complete lecture given by Mel Goodale is available at http://www.crsitd.com/images/Goodale/Goodale/Presentation_Files/index.html.

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(Gordon, 2000) as well as of computational analyses of vision (see Marr, 1982) and of ethological studies of behaviour (Timbergen, 1972).

Although the second is more recent than the first, as well as conceptually distinct from it, these two senses of “integrative” are related. In fact, a multilevel approach to the mind/brain (the second sense) may prove critical for understanding how the brain performs complex, behaviourally important tasks that require integration of diverse brain and bodily functions (the first sense). Thus the contributions contained in this issue may be termed “integrative” in both these senses. In addition, the present papers also often combine results from a variety of empirical techniques, going beyond a strict focus on patient data to include neurophysiological, developmental, psychophysical, and behavioural methods. This “converging operations” approach is not new to perceptual research (Garner, Hake, & Eriksen, 1956), and it has been strongly advocated, for instance, in the interpretation of mental chronometry results (Posner, 2005). It may be thought of as a third way in which the approaches reported in this issue should be regarded as “integrative”. By comparing findings from different methodologies, investigators not only identify converging results that bring greater plausibility to theoretical predictions, but are also naturally led to tap the mind/brain at different levels of analysis. In a sense, they are forced to address the complexity of the relationships between different mechanisms.

We suggest that key to these triply integrative approaches is what may be termed a broad cognitive–neuropsychological stance. Cognitive neuropsychology investigates normal cognitive processes by looking at impairments of cognition at the functional level (Ellis & Young, 1988). For the sake of conciseness, we do not discuss here whether considerations of how brain structure relates to psychological function (the domain of neuropsychology proper) are also needed within such a research approach. In general, we also avoid here the issue of the relationship between cognitive neuropsychology and neuroscience in general (see Caramazza & Coltheart, 2006). Our point here is that cognitive neuropsychology

mostly focuses on patient data—modifications of cognitive processes due to lesions or pathologies of the adult or developing brain—and a significant portion of the work described in this issue is indeed based on patient data. Interestingly, however, other methods can also be used to bring empirically interesting cognitive modifications under a researcher’s attention.

One such method, for instance, involves studying potential dissociations in behavioural measures on identical stimulus materials and tasks, when different types of responses are collected. Indeed, a lively debate has arisen concerning the extent to which verbal estimates or nonverbal matching operations of some object property (deemed as “perceptual” responses) can be dissociated from motor responses on the same property (Bruno, 2001; Carey, 2001; Franz, 2001; Glover, 2001). How such behavioural dissociations should be compared (if at all) to the classic single- and double-dissociation data is a subject that will require further methodological analysis (for discussions, see Dunn & Kirsner, 2003; Van Orden, Pennington, & Stone, 2001). There is no doubt, however, that consistent results from patient double dissociations and behavioural dissociations in healthy individuals form a compelling basis in support of theoretical hypotheses. Another source of evidence involves similar task-related dissociations as a function of different stages of normal cognitive development. Still others include combinations of neurophysiology and behavioural data, as well as the most obvious transcranial magnetic stimulation (TMS)-induced short-term modifications.

The papers in this collection consist of four review articles and nine reports of original research. For the purposes of this introduction, we group them into four general categories.

A dichotomous visual system and modularity

Over the last decade, theories positing a dichotomous conception of higher level visual processing (Milner & Goodale, 1995, 2008) have gained increasing support. To understand the visual system, these theories argue, we must recognize

that vision serves two broad functions: supporting the recognition and identification of objects, people, and events (“vision-for-perception”, identified with the ventral stream from V1 to infero-temporal cortex, IT), or guiding goal-directed actions (“vision-for-action”, identified with the dorsal stream from V1 to posterior parietal cortex, PPC).

These two functions pose quite different constraints on visual processing. Recognizing objects involves consciousness and representations that remain stable over spatial and temporal transformations. For this reason, vision-for-perception privileges context-sensitive, allocentric representations (relations are crucial to constancy processes). Guiding actions, conversely, is much more concerned with monitoring “here and now” relations between effectors and action goals. For this reason, vision-for-action represents objects relative to the current state of relevant effectors, using egocentric rather than allocentric representations. Phenomenal consciousness would be less important to this aim. Given the different computational constraints on the two functions, it would make sense for the visual system to be constituted by separate modules that may be distinguishable both anatomically and functionally.

In an influential book, Fodor (1983) proposed several criteria for modularity, including encapsulation with respect to other mental systems, implementation in specific neural structures, and specific breakdown patterns after damage. While the validity of Fodor’s conception has been debated (Carruthers, 2006; Samuels, 2006), there is little doubt that understanding how, and to what extent, the functional components of the mind can be understood as independent modules is a key challenge in cognitive neuropsychology (Barrett & Kurzban, 2006; Caramazza, 1992; Coltheart, 1999). In his review, Goodale (2008) takes on this challenge. He presents an impressive body of evidence supporting the idea that these two visual functions, although coordinated in everyday visual tasks, are indeed independent and dissociable in specific conditions.

One line of evidence in this regard comes from patient and brain imaging data. In the striking

phenomenon of “blindsight” (Weiskrantz, 1986), for instance, patients with cortical scotomas can point to visual targets presented in blind areas of their visual field, but report that they have no experience of having seen those targets. Patients with visual form agnosia, such as the much-studied D.F. (Milner, 1997), cannot identify the objects they see, and yet they can reach for and grasp them in ways that are comparable to those of a healthy control. Patients with optic ataxia, conversely, perform normally in recognition and identification tasks, but exhibit characteristic difficulties when attempting to grasp objects. Given brain imaging results documenting ventral lesions in agnosics and dorsal lesions in ataxics, such double dissociations are exactly what one would expect if the two visual functions were performed by separable brain modules.

However, each patient is a snowflake (Caramazza & Coltheart, 2006), and the interpretation of individual patterns of brain lesion and corresponding behavioural deficit can be problematic (see Pisella, Binkofski, Lasek, Toni, & Rossetti, 2006; Schenk, 2006). In part for this reason, Goodale (2008) also reviews a number of studies testing perceptual and motor responses on visual illusions in healthy participants. The rationale behind such tests stems from the fact that visual illusions are contextual effects. For instance, in the Ebbinghaus–Titchener illusion, the same disk appears larger when surrounded by smaller disks, and smaller when surrounded by larger disks (a size-contrast effect). In an influential paper, Aglioti, DeSouza, and Goodale (1995) hypothesized that the representation of the disk’s size used by vision-for-action should be immune from the effect of the surround. To grasp the disk, he reasoned, what is important is the size of the disk in relation to the current opening of the fingers, not to the surrounding disks. Thus, one should find that the kinematic parameters associated with a reach-to-grasp movement are not influenced by the disks, even though they of course influence the conscious perception of the targets. In other words, one should find that the size representation used to guide the grasp is different, and dissociable, from

that driving conscious perception. This counterintuitive prediction was confirmed by Aglioti's experiments and started a flurry of research. In his review, Goodale (2008) discusses several studies reporting replications of this basic finding with other illusions or motor responses, as well as some studies that instead reported failures to replicate the finding. Based on his assessment, he suggests that although some controversy remains, the weight of the evidence favours dissociable visual processes for perception and grasping under certain conditions.

In a second review, Franz and Gegenfurtner (2008) take a different stand. They examine comparisons of perceptual and grasping responses to the Ebbinghaus–Titchener illusion (including studies that are considered replications of the Aglioti study and studies that are not) to show that effects of the illusion on grasping are in fact quite consistent across studies if appropriate metrics are employed to summarize the results. They also show that perceptual measures are less consistent, but can be reconciled by adopting some methodological precautions. In addition, according to these authors, the observed effects on perception and action are generally comparable, in turn suggesting that the original finding on the Ebbinghaus–Titchener illusion may not support dissociable processes after all. While the debate on the extent of behavioural dissociations in different types of illusion and motor responses continues (for a review of pointing on the Müller-Lyer illusion, see Bruno et al., 2008; for a similar review of grasping on the Müller-Lyer, see Bruno & Franz, *in press*), we predict that the issues raised in these two reviews will stimulate further research, possibly leading to a definitive clarification of the conditions under which motor responses can be shown to be independent of visual consciousness.

An intriguing example of a novel research direction addressing potential perception–action dissociations is provided by Anema et al. (2008). Instead of testing visual size illusions, Anema and her collaborators compared perceptual and grasping responses to haptically perceived objects. It has been known for a long time that

haptic sizes are perceived as larger in areas of high receptor density such as the hand than in areas of lower receptor density such as the forearm (Weber, 1834/1978). The phenomenon is sometimes referred to as Weber's illusion, although of course the origin of the misperception lies not in the stimulus context to the judged object. As in classic visual illusions, Anema and her collaborators document a dissociation of the perceptual and grasping responses, suggesting that different mechanisms may be operating in the grasp and perceptual report. Unlike the putative visual illusion effects, however, the dissociation reported in the paper is not one whereby grasping is accurate, and perception is biased. Instead, Anema and her collaborators find that perception shows the Weber-type bias (larger sizes on high-density area), whereas grasping show the opposite (larger sizes on low densities).

The type of dissociation fits the idea that the system controlling the grasp responds to increased uncertainty about the true size (due to lower receptor density) by increasing a "safety margin" in the opening of the fingers, whereas the perceptual system simply takes the receptor-mediated size estimate at face value. Thus, the dissociation is quite consistent with the idea that different functions correspond to different perceptual and sensorimotor processing constraints. In the haptic perception of size, which is normally achieved by manipulation, distortions occurring at other body sites are relatively unimportant and may well be tolerated to maximize efficiency in other perceptual tasks, such the identification of the touched limb. In guiding a grasp to the object, instead, efficacy is equally important at different body sites. Therefore, to perform an accurate grasp it makes sense to take into account uncertainty about size when processing the hand aperture.

Another contribution is provided by the study of Nardini et al. (2008), which looks at the development of integrative processes for action- and perception-related information in children. This approach may be construed as exploiting another of Fodor's (1983) criteria—namely, that independent modules exhibit characteristic ontogenetic

pace and sequencing. This criterion has been used repeatedly in developmental work on domains such as spatial cognition (Hermer & Spelke, 1996), language and “theory of mind” (Scholl & Leslie, 2001), object individuation (Leslie, Xu, Tremoulet, & Scholl, 1998), and motor control (Adolph, 2000). The study of Nardini and colleagues applies the concept to a memory task whereby children had to recall which box held a toy. Each box used in the experiments was identified by a unique combination of surface properties (for instance, a specific colour) and actions (for instance, a specific method to open the box—using a hook, or pushing a curtain).

After comparing two- and three-year-old children, the results reveal a set of asymmetries in the integration of the surface- and action-related properties. Two-year-olds used the action-related properties but disregarded colours; three-year-olds used actions and colours but neglected texture; both groups used faces. Such uneven integration of surface- and action-related information is consistent with different mechanisms for processing the two types of information, suggesting that they mature at different paces. Interestingly, the differences between colour, texture, and faces also indicate that, at least for this type of task, the developmental changes are best described as involving several functional subsystems rather than a single, unitary ventral system. This interpretation echoes similar proposals for multiple substreams within the dorsal stream (Jacob & Jeannerod, 2003; Pisella et al., 2006; Rizzolatti & Matelli, 2003), pointing to the possibility that a strictly dichotomous conception of visual functions and of its underlying neural structure might be too rigid and might need to be substituted by a more articulated view.

Finally, an interesting study of perceptual and motor-related localization processes is offered by Shi and de’Sperati (2008). During our everyday interactions with the world, the ability to localize objects adequately is undoubtedly important. An intriguing complication, however, is that sometimes the objects that we need to localize may be moving—for instance, when we need to catch a ball, or grab an apple before it falls on the

ground. Due to processing delays, localizing a moving object may require the ability to extrapolate the future location of the processed object and to combine this with information about other stationary objects as well as eye and body positions. A phenomenon, among others, that is generally thought to tap into such extrapolation processes is the flash–lag effect: A stationary object that is flashed in alignment with a moving stimulus is perceived to lag behind it (Nijhawan, 1994). In contrast with previous assessment of the flash–lag, which employed a nulling technique, the experiment of Shi and de’Sperati measures the perceived locations of the stationary and moving stimuli independently, to show that the effect is in fact the outcome of a linear combination of two absolute localization mechanisms—one for the stationary flash and another for the moving stimulus. These results provide a useful baseline for future studies of motor responses to a moving stimulus, such as pointing or saccading, which might provide insights on the integration of perceptual and motor extrapolation mechanisms, as well as on conditions whereby they might be dissociated (Kerzel & Gegenfurtner, 2005).

Integration and “offline” processing

As stated by Goodale (2008), understanding the integration of different visual functions will ultimately require that we specify the nature of interactions and trading of information between streams. A key issue here is that of processes that are not directly driven by a currently available stimulus (“online” processing) but require accessing internal representations (“offline” processing).

A simple example of the integrative processes that come into play in such situations is provided by the effect of delaying the initiation of open-loop grasping after the presentation of a visual stimulus, a situation that appears to shift the metrics of the grasp from observer- to object-relative (see, for instance, Hu & Goodale (2000); Westwood & Goodale, 2003). Such shift is exactly what one would expect if the representations involved in the delayed grasp were provided by slower, but longer lasting, perceptual

mechanisms when online visual information is no longer available due to the delay (for a similar effect on saccades, see de'Sperati & Baud-Bovy, 2008). Such representations may be computed by a ventral stream-prefrontal pathway, bypassing the parietal areas (Pisella et al., 2006). Other examples are provided by the processes that come into play during the preparatory phases of learned movements (van Doorn, van der Kamp, & Savelsbergh, 2007) and that may be disrupted by lesions in the more ventral part of the parietal lobe, resulting in apraxia.

In their elegant study, Hesse et al. (2008) address the interaction of perceptual and motor processes by testing whether the orientation of a previously presented distractor object influences the choice of hand orientation when grasping a successive target object. The paradigm may be considered a variation of the visuomotor priming technique (Craigero, Fadiga, Umiltà, & Rizzolatti, 1996). In contrast to classical visuomotor priming, however, the current study not only measures reaction times for congruent or incongruent target–distractor pairs, but also records movement kinematics. This is a crucial variation, because reaction times may not fully reflect the use of prior information if participants move before having processed all the information needed for that movement (van Sonderen & van der Gon, 1991). Results indicate that the orientation of the distractor influenced the choice of grip orientation, despite the fact that the target object was continuously visible during the preparatory phase as well as during the execution of the grasp. Thus, at least some aspects of the kinematics of a grasp are not based solely on real-time information, but can be affected by processing that occurred before the preparation of that particular action.

A closely related issue is addressed in the study by Mirabella et al. (2008). They asked participants to perform speeded reaching movements towards visual targets in two conditions. In one condition, which they call the go-only task, participants had to move from a home position to a target position as soon as a target dot appeared. In a second condition, called the countermanding task, participant again performed the go-only task in most trials,

but these trials were randomly intermixed with stop trials. In stop trials, a stop signal followed the appearance of the target dot, and participants were required to cancel the pending movement and remain at the home position. It has been known for a long time that introducing such stop trials increases participant's reaction times in comparison to a pure go-only session. Given that a stop signal may come out, it makes sense to maintain a general readiness for inhibiting the movement, and this is likely to slow the response (Lappin & Eriksen, 1966). Not surprisingly, Mirabella and colleagues found exactly this: In the go-only condition, participants had lower reaction times.

But Mirabella and his colleagues (2008) also found something else. The moving times were also affected by the conditions, but in a manner opposite to that of the reaction times. Slower reactions tended to correspond to faster movements, and vice versa. This pattern was visible in most participants even on a trial-by-trial basis. Mirabella and colleagues suggest, quite plausibly, that this unexpected pattern is due to strategic changes in the way the movement is programmed under different cognitive contexts and expectations. When the response is more predictable, participants start with a rough motor programme and use feedback to a greater degree (hence a faster reaction time but a longer movement time). When the response is uncertain, the longer preparatory phase allows for movements to be performed in a more ballistic fashion, with less feedback-driven control and faster times. As for the study of Hesse et al. (2008), therefore, the execution of the action was not based solely on online information. Rather, the weight given to online information was modulated by information provided before the action was performed.

Also relevant to the issue of preparatory processes in action plans is the study by Chiavarino et al. (2008), who tested difficulties of parietal patients in imitating multicomponent actions. Chiavarino and colleagues asked parietal and frontal patients, as well as healthy controls, to imitate the experimenter while she put a goal object over a goal location in a certain goal orientation. A pilot study of error rates for these three

goals indicated that the choice of object is given the greater importance in this sequence (i.e., has the lowest error rate), followed by orientation and finally location. The results of the experiment suggest that, in comparison with frontal patients or controls, parietal patients were impaired in choosing correct orientations. In a separate measure of their perceptual judgements of orientation, however, these patients performed well, suggesting that they might be able to imitate orientation if the task were set up so that orientation became the main goal of the sequence.

To test this possibility, Chiavarino and colleagues (2008) performed a second study. In this study, participants were required to imitate a slightly different multicomponent action: picking up an object with the thumb and either the index or middle finger (goal finger), followed by bumping its yellow or black end (goal direction) on the table, followed by putting it on the table on a vertical or horizontal line (goal orientation). Although orientation was the last action in the sequence as in the previous experiment, the analysis of pilot error rates indicated that under these conditions it now became the main goal, followed by direction and finally by finger. Chiavarino and colleagues report that with the new sequence the performance of parietal patients improved and became comparable with that of the frontal ones. This finding is consistent with the idea that, during the preparatory phase of a multicomponent action, cognitive resources are allocated to different goals in accordance with the relative importance of those goals in a hierarchy. When such resources are restricted, for instance due to a brain lesion, processing of a given goal may be spared, or impaired, depending on the position it occupies in the hierarchy and therefore on the resources allocated.

Perception, action, and subcortical processing

Misconceptions about their nature have often denied a scientific status to emotions (Zhu & Thagard, 2002). However, cognitive scientists are

growing increasingly aware of the importance of affective factors in human cognition (see, for instance, Davidson, 2000). An obvious domain for affective processing is the integration of perception and action. In the natural environment, enhanced processing of threatening or rewarding stimuli might be important for survival. Brain mechanisms permitting more rapid or more efficient processing of perceptual or visuomotor information in the presence of stimuli with affective valence would therefore be highly adaptive (Sokolov, 1990).

To test the effect of affective valence on motor processes, Csathó et al. (2008) employ a targeting task, which involves moving a cursor over a target object. Immediately before the presentation of the target object, they also show distractor pictures of threatening, neutral, or, in a control study, positive-valence images. The results indicate that the efficiency of the targeting movement is modulated by the affective valence of the distractor. Specifically, participants were generally faster and less affected by target distance after a threatening distractor than after neutral or positive distractors. At a functional level, this modulation is therefore equivalent to improving targeting performance for peripheral, more distance targets, while preserving performance in nearer targets—a sort of general enhancement of motor processing that has obvious advantages in reacting to a potential threat.

Csathó and his collaborators (2008) interpret these findings in terms of a rapid visuomotor “alarm system” involving the superior colliculus, brainstem amygdala, and frontal cortex (Liddell et al., 2005), bypassing the geniculostriate pathway. In support of this interpretation, they perform two additional studies to demonstrate two other features of the modulation—namely, that it goes away if stimuli isolate S-cone receptor function, and that it shows a nasal-versus-retinal hemifield asymmetry. Because the superior colliculus receives no direct S-cone input from the retina and is known to be asymmetrically activated from the temporal and nasal hemifields, the results of these two additional experiments provide corroborating evidence for their interpretation.

Hypnosis is also a phenomenon that involves affective and motivational processes. In a

comprehensive review, Carli et al. (2008) present a number of experimental findings that suggest differences in sensorimotor integration between highly or poorly hypnotizable individuals. These differences are intriguing, because the ability to comply with hypnotic suggestions has been attributed (Bowers, 1992) to the disengagement of an attentional executive system involving frontal and limbic structures (see Norman & Shallice, 1986), which in turn causes a release of lower level control systems, possibly involving automatic sensorimotor integrative processes (for a similar view on the release of internally generated smooth pursuit eye movements during the drowsy state, see de'Sperati & Santandrea, 2005).

Carli and his collaborators (2008) examine sensorimotor integrative processes at two levels: reflexes and the control of posture. Their findings suggest that highly hypnotizable individuals show enhanced inhibitory influences on the spinal control of motoneurone excitability, as well as specific changes in postural control under attention-taxing conditions. Interestingly, Carli and his collaborators suggest that hypnotizability effects on posture may be related to activity in the locus coeruleus, a nucleus in the brain stem that has been related to physiological responses to stress and fear. Besides their implications of theories of hypnosis, these results may contribute to clarify possible neural circuits integrating perceptual and action-related information within automatic, nonconscious processes. It might be interesting, in this respect, to further examine hypnotizability-related differences in more complex motor tasks, such as reaching and pointing.

Peripersonal space, tools, and meaning

The last category of papers in this issue addresses diverse issues such as the role of multisensory integrative processes in the representation of peripersonal space, the use of tools, and the interaction of gestures and words when we communicate. Common to these research interests is an issue that might be broadly defined as related to the processing of meaning.

The integration of perception and action involves semantic processing—for instance, when we learn how to use tools by observing others that use them. This type of learning may be achieved by attempting to replicate the observed actions as closely as possible (imitation). Alternatively, an individual may perceive the affordance (Gibson, 1979) of a tool by processing its visible properties and then verify it by paying attention to the outcome of an observed action. This type of nonimitative learning has been called emulation (Tomasello, 1990). In their paper, Lunardelli et al. (2008) study this type of nonimitative learning in patients with brain damage. They asked patients with left- and right-hemisphere brain damage to perform different tool use tasks after exposure to different instruction conditions, including demonstrations of the correct usage and failed attempts. The results indicate that patients with left-hemisphere damage performed more poorly than controls. This finding is consistent with the idea that the left hemisphere has a special role in the representation and planning of goal-directed movements, a proposal that is also supported by behavioural data reviewed by Goodale (2008). In addition, in both patient groups imitation was still the most frequent learning mechanism. However, patients with left-hemisphere damage also tended to use alternative, nonimitative strategies more often than those with right-hemisphere damage. Because this patient group suffered lesions that caused greater impairment in their ability to imitate, this finding is consistent with the idea that the cognitive processes supporting emulation are different from those supporting imitation and remain to some extent available even when the latter are damaged.

But using tools also involves more basic integrative processes. To be able to use them, we must be able to plan actions related to the tools, and in some way integrate them with the representation of our own body and its motor capabilities. A key role in this respect is therefore played by the integration of multisensory information in representing the space immediately around us and our body. In their review, Lådavas and Serino (2008) address this issue with special attention to plastic

changes in the representation of peripersonal space after tool use. In the striking phenomenon called cross-modal extinction, right-brain-damaged patients fail to detect tactile stimuli on the contralateral hand when a concurrent visual stimulus is presented to the ipsilesional hand. The phenomenon is specific to peripersonal space, because a visual stimulus in the ipsilesional hemifield, but presented far from the hand, fails to elicit the effect (Farnè, Demattè, & Làdavas, 2005). After experience with a tool that effectively extends the range of reachability for objects, however, cross-modal extinction can be observed even far from the hand, within the portion of space that had become reachable due to the tool (Farnè & Làdavas, 2000). This finding extends previous data from monkey neurophysiology (Iriki, Tanaka, & Iwamura, 1996) and suggests that the representation of personal space is plastic and can be modified by experience with objects that extend the range of possible multisensory interactions, including tools in the standard sense but also devices such as a blind cane, mirrors, and even body shadows (Pavani & Castiello, 2004). Làdavas and Serino examine various factors that may be involved to produce such plastic modifications, arguing that those related to motor functions are crucial.

Finally, in a more traditional study, Bernardis et al. (2008) test interactions between semantic processing for gestures and words. In their first experiment, they presented video-clips of pantomimes followed by words that could be either the names of the pantomimed elements or unrelated words. Video-clips and words were chosen to ensure that they were comparable in recognizability, concreteness, and familiarity. The results revealed interference when the meaning of the gesture and that of the word differed. Stated otherwise, reading times were significantly higher than their baseline for unrelated clip-word pairs, but they were similar to baseline for related pairs. Thus, it appears that the meaning conveyed by gestures does not interact with the meaning of words at the level of the lexicon (such interaction would entail a facilitation effect). Still, the two meanings do interact (as proved by the observed interference).

Presumably, the semantics of gestures is complementary to that of language: The former is analogical and spatial, the latter is symbolic and propositional. Thus, unless a conflict arises, the two formats are automatically integrated into “packages” (Kita, 2000) suitable for speaking and organized according to spatial and motor constraints. When the semantics of gesture and word conflict, however, this automatic packaging process must be undone before the word can be read, hence the increased reading times. This interpretation is corroborated by the results of a second experiment. In this second study, Bernardis and his coauthors recorded event-related potentials during silent reading of words presented as in the first experiment. The results showed a left-hemisphere negative deflection peaking at 400 ms after stimulus onset, a component that is believed to be related to the analysis of meaning (see Holcomb, 1993). In contrast with the typical results obtained with verbal stimuli, however, this component was more spread over the central and anterior parts of the scalp. Thus, this finding is consistent with different brain mechanisms for purely verbal and verbal–gestural packages of meaning-related information.

Conclusions

Integrative approaches to perception and action have proved fruitful in a number of research areas, from the physiological study of goal-directed locomotion in simple animal models, such as the lamprey (Grillner, Kozlov, & Kotalesky, 2005), to larger scale questions pertaining to the functional architecture of the mind in humans, such as those addressed in this collection. The papers collected in this issue address these questions from a broad cognitive–neuropsychological perspective, using a variety of techniques from the study of deficits in brain-damaged patients, to electrophysiology, imaging data, kinematic and postural measures, and mental chronometry. We believe that they provide interesting advancements of our knowledge concerning interactions between perceptual and motor systems in the human mind/brain. Most usefully, they will also contribute to

focus our attention towards issues where knowledge is still lacking.

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