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REVIEW

# The ideomotor recycling theory for tool use, language, and foresight

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**Abstract** The present theoretical framework highlights a common action–perception mechanism for tool use, spoken language, and foresight capacity. On the one hand, it has been suggested that human language and the capacity to envision the future (i.e. foresight) have, from an evolutionary viewpoint, developed mutually along with the pressure of tool use. This co-evolution has afforded humans an evident survival advantage in the animal kingdom because language can help to refine the representation of future scenarios, which in turn can help to encourage or discourage engagement in appropriate and efficient behaviours. On the other hand, recent assumptions regarding the evolution of the brain have capitalized on the concept of "neuronal recycling". In the domain of cognitive neuroscience, neuronal recycling means that during evolution, some neuronal areas and cognitive functions have been recycled to manage new environmental and social constraints. In the present article, we propose that the co-evolution of tool use, language, and foresight represents a suitable example of such functional recycling throughout a well-defined common action–perception mechanism, i.e. the ideomotor mechanism. This ideomotor account is discussed in light of different future ontogenetic and phylogenetic perspectives.

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## Introduction

The evolution of the human brain and its cognitive functions represents an important theme for the domains of neuroscience and cognitive psychology (Finlay et al. 2001; Güntürkün 2012). Various cognitive capacities, such as tool use (Osiurak 2014), language processing (Berwick et al. 2013), and remembering the past and the future (also called foresight capacity for the future, Suddendorf and Corballis 2007), or calculation (Dehaene and Cohen 2007), are also partially shared by other non-human animals, but our species reveals the highest potential. For instance, only humans are able to use a tool to create another one (Osiurak 2014), but more importantly, only humans are capable of vocally describing, with great detail, how they will use a tool or several tools in a future episode. This foresight capacity associated with language can afford the human species a specific survival advantage (Suddendorf and Corballis 2007). If a person is able to verbally describe potential dangerous future scenarios, she/he can adapt or avoid future behaviours to efficiently manage such environmental constraints.

The link between language and foresight has been hypothesized by Gärdenfors (2004) as follows: "There has been a co-evolution of cooperation about future goals and symbolic communications" (p. 243). According to Corballis (2013), language could be the most efficient skill to communicate non-current episodes, that is, the capacity to imagine outcomes of future scenarios. This ability to envision the future sharpened by the language capacity represents an interesting example of anticipative mechanism.

From this perspective, the human brain seems more anticipative than reactive to environmental constraints (Kunde et al. 2007). Moreover, for Koziol et al. (2012), "Evolutionary processes favored the development of predictive or "anticipatory," and simulative or "imaginative" mechanisms for the purpose of action control and not for cognition per se." (p. 507). The main goal of the present article is to present an anticipative action control hypothesis dedicated to high cognitive functions such as tool use, human language, and foresight capacity.

Our general hypothesis is as follows: if tool use, language capacity, and foresight have evolved in a mutual way during hominid evolution (Corballis 2009, 2013; Gärdenfors 2004), then some similar cognitive mechanisms could be currently detected for such high cognitive functions. To identify one of these hypothetical common cognitive mechanisms, we have capitalized on the concept of neuronal recycling (Anderson 2010; Badets et al. 2016; Dehaene and Cohen 2007). Regarding the neuronal recycling account, an old inherited neuronal network has been recycled for higher cognitive functions in humans. For example, Dehaene and Cohen (2007) suggested for human language that "human speech and communication recycles a pre-existing primate system for hierarchical auditory representation, initially non-specialized for speech processing" (p. 393). This hypothesis for higher cognitive functions, such as language, has already been debated by scholars (Anderson 2010; Dehaene and Cohen 2007; Gallese 2008), but in the present article, we will develop the hypothesis that a *common* action–perception mechanism has been recycled for several and different cognitive functions. To anticipate our conclusion, we will defend the thesis that a common ideomotor mechanism has been recycled to afford a common anticipative mechanism shared between tool use, language, and foresight.

The first part of the paper will present the main idea about the co-evolution of language and foresight (Corballis 2009, 2013; Gärdenfors 2004). The second part will present the notion of "neuronal recycling", which, for neuroscience and cognitive psychology, can be defined as a recycling of an old inherited mechanism for new environmental and social/cultural constraints (see Anderson 2010 for the main theory; Dehaene and Cohen 2007; Gallese 2008 for comparable perspectives). The third part will present a definition of the ideomotor mechanism as a candidate for such recycling account (Badets et al. 2016; Badets and Rensonnet 2015; Badets et al. 2016; Badets and Osiurak 2015b). The subsequent four sections will discuss the ideomotor recycling account in the domains of tool use, foresight, and human communication (i.e. non-verbal and verbal communication). Finally, the last section will offer future empirical directions from phylogenetic and ontogenetic perspectives.

## Co-evolution of language and foresight

Language and foresight capacity have most likely evolved together for at least 2 million years (Corballis 2010). This hypothesis predicts a gradual emergence of language and thus contradicts its sudden appearance within the past 100,000 years, as suggested by Chomsky (2010; see also Tattersall 2012). For Suddendorf and Corballis (2007), the ultimate advantage from an evolutionary viewpoint is the mental capacity to imagine the future and to describe it vocally. The co-evolution of foresight capacity and language has revealed a more efficient representation of the future in describing vocally, with prodigious accuracy, various prospective events such as objects, people, or places in the environment (Corballis 2013). As suggested by Corballis (2013), there is a controversy among scholars for the earlier origin between language and the foresight capacity. However, it seems that rats are able to replay or pre-play their behaviour in spatial environment (Pfeiffer and Foster 2013). This evidence can suggest that the foresight capacity has probably an earlier origin than language evolution in humans.

This co-evolution can be also assumed in the concept of narration, which represents a key feature of human language (Dessalles 2007). People can repeatedly explain past, current, and future events to others in order to improve their lives. As suggested by Milojević and Inayatullah (2015) on the concept called "narrative foresight" "if we are to engage in a process aimed at the deeper understanding of alternative – possible, probable and preferred - futures then it is also crucial to engage with the worldviews, stories, myths and metaphors that underlie them." (p. 161). Accordingly, the stories developed throughout narration can give a survival advantage to human because they can anticipate wished or non-wished future scenarios. These narrative items throughout myths and metaphors can be stored and transmitted to future generations.

Importantly, the scenario that we will develop in this article is established throughout the link between tool use, spoken language, and foresight capacity. From this perspective, tools can be defined as manipulable objects that can enhance/improve motor behaviour (Osiurak et al. 2010; Osiurak and Badets 2016). Consequently, tool-use efficiency involves a tight coupling between several cognitive capacities and motor skills. In humans, it has been suggested that from approximately 2.6 to 1.6 million years ago, the emergence of tool use could represent a possible starting point for foresight and spoken language development inside a narrative account (Corballis 2013; Gärdenfors and Osvath 2010; see Harmand et al. 2015 for an earlier emergence of tool use approximately 3.3 million years ago; Plummer 2004). Obviously, tools for future use are fundamental to survive in environmental uncertainty and could constitute the core of prospective cognition in humans (Gärdenfors and Osvath 2010). For Corballis (2013), "The emergence of tools may have added complexity to the activities of these early hominins, and indeed to their mental time travels, creating further selective pressure toward more effective communication." (p. 3). Accordingly, Corballis (2009, 2013) has suggested that tool use orients humans to pedagogy skills through vocal language or simply in the goal to explain what we are doing (or what we will do) specifically with tools (the narrative account). This evolutionary argument is also developed by Stout and Chaminade (2012) when they suggest that "intentional pedagogical demonstration could have provided an adequate scaffold for the evolution of intentional vocal communication." (p. 82).

However, from this phylogenetic history, we could ask how such communicative and foresight capacities have been so tightly coupled in humans. What is the specific mechanism that could permit such coupling within the past 2 million years? Part of the answer might stem from a fundamental principle of the human brain called neuronal recycling (Anderson 2010; Dehaene and Cohen 2007). In this view, an old inherited neuronal network and its associated cognitive function are exploited, recycled to manage more sophisticated and new environmental constraints. The next section presents this principle concerning the human brain.

## The notion of neuronal recycling

In neuroscience and cognitive psychology, the notion of neuronal or cognitive recycling has been theorized through the redeployment hypothesis (Anderson 2010), the neural exploitation hypothesis (Gallese 2008), the neuronal recycling hypothesis (Dehaene and Cohen 2007), and the cognitive recycling hypothesis (Badets et al. 2016). From an evolutionary viewpoint and as suggested by Anderson (2010), there is a "simple observation that evolutionary considerations might often favor reusing existing components for new tasks over developing new circuits de novo." (p. 246). Accordingly, a fundamental principle of the human brain is to recycle an old inherited brain network to permit adaptations to new social and/or environmental constraints. This fundamental principle is functional during the phylogenetic (i.e. brain evolution perspective) and ontogenetic history (see Badets et al. 2016 for a cultural recycling hypothesis for different ontogenetic examples like written words, tool use, or arithmetic).

One phylogenetic example of such a neuronal recycling mechanism comes from the foresight capacity as mentioned above in this article. Indeed, like humans, rats are able to replay or pre-play their behaviour in environment (Pfeiffer and Foster 2013), but more importantly, both species show comparable hippocampal activity during these tasks. For Corballis (2013), this neuronal evidence could reflect a strong continuity between species for the capacity to envision the future. Consequently, the possibility exists that a pre-existing hippocampal function for foresight in mammals has been exploited, recycled during hominid evolution for a more sophisticated capacity to envision the future in humans (Suddendorf and Corballis 2007). In a same vein, Gallese (2008) suggested the same mechanism for language evolution in humans and consequently its link with basic sensorimotor system "When in the course of evolution selective pressures led to the emergence of language, the same neural circuits in charge of controlling the hierarchy of goal-related actions might have been "exploited" to serve the newly acquired function of language syntax." (p. 327). These phylogenetic examples on language and foresight will be developed in chapter 7 and the last section "Future directions and conclusion", respectively.

Importantly, Anderson (2010) suggested that such a neuronal recycling principle could be efficient for new cultural constraints without losing the function of the original mechanism. Consequently, when a person engages in a cultural task like in arithmetic or tool use, it might be possible to detect behavioural traces from the old inherited cognitive mechanism (see also Badets et al. 2016; Anderson and Penner-Wilger 2013 for this behavioural–neuronal trace hypothesis).

For the present review, if we postulate that a well-identified action–perception mechanism has been recycled for tool use, human language, and the foresight capacity, then, in such domains, its implication should be detectable at a behavioural level. After presenting the action–perception mechanism for our recycling account, the next sections will present empirical and/or theoretical evidence of such interpretations in tool use, foresight, non-verbal communication, and language.

## The ideomotor mechanism

The original function of the ideomotor mechanism is mainly devoted to perceptual anticipation for action regulation (James 1890; Greenwald 1970; Hommel et al. 2001). In this theory, goals have a higher priority than movement itself (Badets and Osiurak 2015b; Iacoboni 2009; Osiurak and Badets 2016). Specifically, action regulation is mainly managed by the expected perceptual consequences that it aims to generate in the environment. In experimental psychology, the idea that actions are planned in terms of mental anticipation of the intended outcome was prevalent in the nineteenth century as the ideomotor theory to voluntary action (James 1890). The ideomotor theory has generated a great deal of research during the last 40 years, particularly inspired by the idea of common coding of perception and action (Prinz 1997) and the subsequent elaboration into a theory of event coding (Hommel et al. 2001). The main idea is that actions are planned in terms of anticipated sensory consequences, so that the representation of actions and representations of stimuli in environment share a "perceptual" format (i.e. both refer to sensory events).

There are three experimental paradigms for exploring the role of anticipation of perceptual action consequences in action control: the action–effect learning paradigm, the response–effect compatibility paradigm, and the action–perception race paradigm (see reviews by Badets and Osiurak 2015b; Koch et al. 2004; Nattkemper et al. 2010; Shin et al. 2010; Waszak et al. 2012). The action–effect learning paradigm is based on the idea that a learning phase is required to consistently connect motor output with specific perceptual consequences. After this action–effect learning has taken place, features of the learned action effects, if presented as stimuli, can prime the associated actions if they precede action choice (see Elsner and Hommel 2001; Greenwald 1970). It could be argued that such learned action effects, if that are constantly perceived, can cause a circular reflex problem in producing the associated action, over and over again (Greenwald 1970). However, in a recent theoretical formulation of the ideomotor mechanism, Kunde et al. (to appear) suggested that such problem can be avoided because intended action could be coded in terms of transition between two perceptual expectations: a current and an intended one. If after enactment there is no discrepancy between the two expectations, there is no reason to retrieve over and over again an action.

Note, however, that the ideomotor approach aims to explain voluntary action, so that it would be most convincing in a more functional sense to demonstrate that effect anticipation contributes to action control when it is not triggered by an external stimulus, as in the action–effect learning paradigm, but by an internally triggered "mental cue" (see Keller and Koch 2006; Waszak et al. 2005). This idea is explored by the response–effect compatibility paradigm (Koch and Kunde 2002; Kunde 2001). Here, the idea is that pre-existing associations based on overlap on some relevant dimensions (see Kornblum et al. 1990, for the notion of "dimensional overlap") can be used to manipulate the compatibility of responses and their ensuing effects (Kunde 2001). For the third paradigm (i.e. the action–perception race paradigm), it has been shown that the ideomotor mechanism could be central to efficient behaviour like tool use (Badets and Osiurak 2015b for a review; Osiurak and Badets 2016 for the theory: Massen and Prinz 2007a, b, 2009 for reviews; Sutter et al. 2012). Without denying the importance of the link between action and perception, the action–perception paradigm aims to assess which mechanisms are the most important for the task. In other words, there is a race between the mechanism of the action and the mechanism of the perceptual consequence of this action. For example during a tool-use task, the representation of the action is based on the motor parameters in order to manipulate the tool but also on the perceptual effect that the tool will create in the environment. Clearly, it has been shown in different paradigms that the perceptual effect of the tool represents the most important part of the representation of the action during tool use (Osiurak and Badets 2016).

From an evolutionary perspective, the ideomotor mechanism is present in the central nervous system in humans and non-human animals (see Badets et al. 2016; Shin et al. 2010; Stock and Stock 2004, for reviews, and Meck 1985 for an animal reinforcement study). In this spirit, Cisek and Kalaska (2001) suggested that it is obvious that this mechanism "reflects the ancestral heritage of cognition itself—the perception–action linkages present for millions of years in the functional architecture for situated interaction" (p. 883). For these authors, this anticipative mechanism was functionally active in ancestral animals, and consequently, well before high cognitive mechanisms and cognitive representations in humans.

On a neurophysiological level, premotor and inferior parietal cortex activations are involved during an ideomotor paradigm where expected effects are emphasized (see Melcher et al. 2013 for the premotor cortex; see Pfister et al. 2014 for the inferior parietal cortex). More importantly, an assumption from the ideomotor theory is that action regulation is governed by the expected perceptual consequences in the environment, and consequently, such action representation and stimulus representation share a similar perceptual format (i.e. both refer to perceptual events; see Prinz 1997; Hommel et al. 2001 for this common coding). Accordingly, Schütz-Bosbach and Prinz (2007) suggested that such common coding could be sustained by a neuronal action observation network (AON; Press 2011). In this theory, the premotor cortex, the primary motor cortex, and the inferior parietal cortex are in charge of mapping the observed actions of other people to internal action representation (the "mirror system", e.g. Rizzolatti and Craighero 2004; Rizzolatti and Sinigaglia 2010), as suggested by the common coding hypothesis between perception and action. Mirror neurons were originally discovered in the premotor cortex of macaque monkeys (Di Pellegrino et al. 1992). These cells discharge when the macaque performs an action and when it observes another monkey performing the same action. However, it is important to note that the anatomy, origin, and functions of mirror neurons in human are always debated by scholars in cognitive and neurophysiological domain (see Bonini 2016; Caramazza et al. 2014; Cook et al. 2014; Hickok 2009; for reviews on such controversies). Finally, it is notable that the ideomotor mechanism has been theorized to be involved in the mirror system function (Schütz-Bosbach and Prinz 2007), and Iacoboni (2009) suggests that "mirror neurons embody the overlap between perception and action predicted by the ideomotor framework by discharging both during action execution and during action observation." (p. 659).

To summarize, the ideomotor mechanism has been present in human and non-human animals for several millions of years and finds its neuronal niche in the AON. Interestingly, this ancestral action–perception mechanism could have been recycled for more elaborate behaviours of humans (Badets et al. 2016; Badets and Rensonnet 2015). Based on the behavioural trace hypothesis (Anderson and Penner-Wilger 2013), we have recently demonstrated some empirical evidence that the ideomotor mechanism could be central for number processing (Badets and Pesenti 2011) and tool use (Osiurak and Badets 2014; see also Koch and Kunde 2002, for word processing). Consequently, we propose that no matter the item (i.e. a word, a number, an action, or a tool) that causes expected effects in the environment, such effects represent key features of human intentions. In this perspective, perceptual goals represent the cognitive basis of our different behaviours (see Osiurak and Badets 2016; Schütz-Bosbach and Prinz 2007, for similar accounts). Accordingly, we propose that the ideomotor mechanism can spread its influence beyond motor control and can characterize an important cognitive mechanism to assess higher human functions like tool use, foresight, or language. The next section will extend this theory and will provide theoretical and empirical evidence of the ideomotor account for tool use. Specifically, we will clarify how perceptual goals (and less movement parameters) are cognitive bases for tool use.

## The ideomotor account for tool use

Several cognitive mechanisms are involved in humans during tool use (see Osiurak 2014; Reynaud et al. 2016, for reviews). However, it is now accepted that during tool use, the ideomotor mechanism plays a privileged role in action regulation (Badets and Osiurak 2015b; Massen and Prinz 2009; Osiurak and Badets 2016 for reviews). The expected perceptual effects of tool use in the environment seem essential for different behaviours such as bi-manual coordination (Mechsner et al. (2001), complex tasks such as flying an airplane (Janczyk et al. 2015), or simpler tasks such as using a lever or pliers (Osiurak and Badets 2014; Massen and Prinz 2007a, b). Theoretically, Osiurak and Badets (2016) recently suggested that tool use could be based on reasoning skills rather than on manipulation memories. For the manipulation-based approach, tool use is governed by stored sensorimotor knowledge about how to manipulate tools (Borghi 2004; Buxbaum 2001; Buxbaum and Kalénine 2010). This manipulation knowledge, that is, the actions of the hand on the tool, is stored and retrieved during tool use. For instance, a power grip on a handle represents manipulation knowledge during the use of a hammer. However, without denying the involvement of motor programs, the reasoning-based approach suggests that tool use could be mainly governed by technical reasoning to solve a problem in the environment. If a person wants to hammer a nail (a problem), he or she has to use mechanical knowledge in order to generate the mental simulation of the tool-use action (e.g. a hammer pounding a nail). Then, this mental simulation can guide the selection of the appropriate motor programming to use the hammer. In this way, mechanical knowledge is useful to represent the expected perceptual effect of the tool on the environment. Clearly, the reasoning-based approach is akin to the ideomotor theory, and in the domain of tool use, it has been strongly supported by different paradigms (see Osiurak and Badets 2016 for a review and the theory).

For instance, in using the action–perception race paradigm, Osiurak and Badets (2014) assessed participants in a study mixing foresight capacity and tool-use capacity. In this experiment, participants were required to use a tool after processing a pre-instructed stimulus embedded in an ongoing task (i.e. a classical event-based task, Badets et al. 2012; Einstein and McDaniel 1990). The ongoing task was a recognition task where two figures were presented on a video screen. The task was to decide whether the two figures were identical or not. In some trials, the two figures represented a joker. This joker was the pre-instructed stimulus and required the use of normal or inverse pliers. For normal pliers, the hand and tool movements were identical, that is, a closing or opening movement. In this situation, no race between the hand action and the perceptual effect of the tool on the environment can be behaviourally detected because both movements were identical. However, for the inverse pliers, such movements were opposite, that is, when the pliers required a closing movement to grasp a small object (the perceptual effect), the participant had to open her/his hand (the hand action). Crucially for this paradigm, the figures in the ongoing task were shown to the participants as masks performing an opening or a closing movement. The results revealed that no matter the hand action, compatibility was more efficient between the mask movement and the tool movement. Specifically, when the joker was recognized after a closing or opening movement of the mask, the participants were faster to initiate an action for a closing or opening movement of the tool, irrespective of their hand movements.

Another example comes from an observation paradigm (Massen and Prinz 2007b). In this study, participants were required to observe a model that touched a target by making a lever action. After this observation, the observers performed the task in congruent condition from the prior observation. Specifically, the congruency could come from the lever action (i.e. the perceptual effect of the tool on the environment) or the user (the hand action). Results revealed that participants were faster and more accurate when the action performed by the tool was congruent. This finding suggests that the representation formed during the observation was preferentially based on the perceptual effect of the tool on the environment than on the action performed by the hand. For the ideomotor theory and the reasoning-based approach for tool use, all these evidences reveal that goals have a higher priority than the movement itself (Badets and Osiurak 2015b; Iacoboni 2009).

To summarize, tool use, as action regulation without tool, involves the ideomotor mechanism (Massen and Prinz 2009; Osiurak and Badets 2016). This action–perception mechanism has existed for several millions of years and has been recycled for more elaborate cognitive functions for tools.

## The ideomotor account for foresight

The capacity to envision the distant future is highly developed in humans (see Badets and Osiurak 2015b; Einstein and McDaniel 2005 for reviews). For instance, to plan and trigger our future actions at the appropriate time and place is of primary importance for an autonomous and safe life. In contrast, failing to remember such appropriate actions is dependent on prior intentions and is considered a widespread human error (Reason 1990). Consequently, the capacity to envision the future is dependent on our capacity to delay intention and strongly involves the cognitive representation of different intended actions (see Badets and Osiurak 2015b for a review). This foresight capacity is sustained by a myriad of cognitive functions in human, like attention, encoding, maintaining, and the retrieval of intended action (see Einstein and McDaniel 2005; Ellis 1996 for reviews).

On a neurophysiological level, Decety et al. (1997) reported that the observation of to-be-produced actions was associated with cerebral activation in the regions involved in the planning and generation of actions: the dorso-lateral prefrontal cortex and the pre-supplementary motor area (pre-SMA). Moreover, Frey and Gerry (2006) found significant activity in the pre-SMA when participants were observing actions with the intention of learning them. This part of the premotor cortex is well known to be involved in the visual-motor association components of motor sequence learning (Sakai et al. 1999), especially during the initial step of encoding. From an ideomotor perspective, Elsner et al. (2002) suggested that the pre-SMA and SMA are mainly involved in forming a link between a motor code and sensory events during action learning (see also Frimmel et al. 2016 for a similar finding on SMA). Frey and Gerry (2006) argued that pre-SMA activity increases with the intention of reproducing sequential visual events and, more generally, can be engaged by the intention to learn through observation. Consequently, as originally found by Decety et al. (1997), the pre-SMA is activated by the observation of intended actions and observational motor skill learning associated with intention instruction (Frey and Gerry 2006). Finally, Hashimoto et al. (2011) recently found that the SMA is involved in tasks for the control and execution of intended actions.

More interestingly, Krieghoff et al. (2009) suggested that delayed intentions could be strongly linked to the control of ideomotor actions. In an fMRI experiment, they were able to differentiate between brain activations caused by ideomotor actions and those triggered by external stimuli. Actions were either freely chosen by the participants (internally chosen actions) or selected by imperative stimuli (externally chosen actions), and the motor performances can be observed as internal or external decisions for the intended actions. Note that only internally chosen actions are guided by ideomotor principles, that is, they are selected and performed by the intended sensory expectations. The results revealed that the recollection of internally chosen actions involved the delayed intention network, including the middle frontal gyrus and the inferior parietal lobe (Simons et al. 2006). It is notable that the inferior parietal lobe is a major brain region involved in the encoding of actions for future enactment (Eschen et al. 2007).

On a behavioural level, Badets and Osiurak (2015b) recently reviewed different domains such as prospective memory, action memory, motor skill learning, or tool use where delayed intention seems strongly linked to the simulation of expected perceptual consequence in the environment. Accordingly, the authors suggest that when a person imagines the far future, the cognitive representation is mainly based on expected perceptual consequences of the different intended actions rather than the action movements themselves. Thus, Badets and Osiurak (2015b) suggest that the fundamental role of the ideomotor mechanism in the foresight capacity is to “bond a relation between the intended action and the future ongoing activities for efficient retrievals" (p. 357; but see Verschoor et al. 2013, for a study where action selection and perceptual expectation can be dissociated from a gradual change throughout development). In adults, Badets et al. (2013) tested this claim using an event-based task that is well known in studies of intention memory (Einstein and McDaniel 1990). During this paradigm, participants were required to perform an action (e.g. a key pressing) after processing a pre-instructed stimulus (e.g. a colour), which is itself embedded in an ongoing task (e.g. an object recognition task). Before this event-based task, participants learned the association between a key press and its perceptual consequence represented by a colour. As predicted by the ideomotor theory, the main finding reveals that the intended key press was retrieved faster after the processing of the pre-instructed stimulus only if colour dimensions between the expected perceptual consequence of the key press and the pre-instructed stimulus were similar. Consequently, our foresight capacity is efficient because the ideomotor mechanism can link our intended actions to future relevant perceptual events in the environment.

In summary, neurophysiological and behavioural evidence reveals that the ideomotor mechanism is central to foresight capacity in humans. Consequently, we can assume that this existing inherited action–perception mechanism has been recycled to manage a higher cognitive function such as the imagination of non-current, or future, events.

Interestingly, it has been suggested that from approximately 2.6 to 1.6 million years ago, tool use represents a starting point for the emergence of foresight and language development (Corballis 2013; Gärdenfors and Osvath 2010; Plummer 2004). If the ideomotor mechanism is relevant during tool use and foresight in modern humans, it could be hypothesized that such a mechanism could constitute a possible cognitive starting point for language emergence. The next section will present empirical evidence for the role of the ideomotor mechanism in human communication.

## The ideomotor account in human communication

In the first part of this section, we will present empirical and theoretical evidence that expected perceptual goal is key information for an efficient dialogue between two persons. In this view, the presented studies used observational paradigms where a person (i.e. the receiver) observes another person performing an action (i.e. the sender). Our goal is to demonstrate that during this observation, the abstract meaning associated with an action can be processed by receivers. Finally, despite the lack of direct empirical evidence for the ideomotor account in spoken language, some scholars have theorized for such possibilities. The last part of this section will present the theoretical account for the ideomotor involvement in verbal communication in humans.

### The non-verbal communication

Corballis (2009) stressed that spoken language may have come from a manual gesture system that originated as long as 2 million years ago, and for him, "language evolved from the mirror system in primates, which provides a platform for both the production and perception of intentional bodily acts" (p. 38). Since the eighteenth century, scholars have capitalized on this non-verbal gestural theory for the language evolution in our species (see Corballis 2002, 2009 for reviews). In this theory, actions can represent shared meanings between an actor and an observer. Rizzolatti and Arbib (1998) capitalized on the mirror neuron system for this hypothesis and suggested that the ability to identify goal-directed actions performed by others could represent the evolutionary foundation from which communication, semantics, and language emerged (see Arbib 2005a, b for language evolution; and Heider 1944 for a theory on social perception). According to this attention and goal account between two persons, Tomasello (2008) suggested that "Joint goals also structure joint attention, since acting with a partner toward a joint goal, with mutual understanding that we are doing this, quite naturally leads to mutual attention monitoring." (p. 181). The semantic dimension that forms the core of communication between two people comes from the following steps: (1) an actor performs an action which is probably semantically relevant to an observer. Here, "probably relevant" means that the action is associated with probable important meanings: for instance, a person grasping the last piece of food on the ground; (2) in the brain of the observer, the premotor areas activate, which permits in turn an overt beginning of the same grasping action; and (3) this beginning is understood by the actor, and she/he can speculate on the intention of the observer, that is, to keep the last piece of food for her/him. Adapted to the non-verbal communication theory, but as suggested by the ideomotor theory, perceptual effects on environment are processed between the actor and the observer because they represent common perceptual codes of their intended behaviours.

We have tested this gestural theory for communication using a numerical cognition paradigm (Badets and Pesenti 2010), and we have subsequently revealed that our findings could come from an ideomotor mechanism (Badets and Pesenti 2011; Badets et al. 2013). In this series of studies on non-verbal communication, we have used numbers because these symbols afford implicit semantic knowledge, which is not the case for images, words, or sentences that refer explicitly to concrete objects and actions. In Badets and Pesenti's experiment

(2010), participants were required to verbally enunciate a number after the visual presentation of a grasping movement. Numbers represented a small (2 and 3) or large (8 and 9) magnitude, and the grasping movements were closing or opening the hand. The results revealed that participants were slower to enunciate large numbers after the visual processing of a closing movement. This effect was absent after the presentation of a fake non-biological hand, which suggests that the AON seems preferentially implicated in biological, but not non-biological material. Indeed, it has been shown that the premotor cortex is mainly engaged during the observation of a human model and is less active for a non-biological actor performing the same action (Tai et al. 2004). For the ideomotor approach, this finding reveals that during the observation of a closing movement, the AON activates the important information about the action, that is, the small magnitude for picking up a small object. This small-magnitude activation throughout action impairs in turn the verbal enunciation of large numbers that requires the automatic activation of large magnitudes. For Badets and Pesenti (2010), this discovery represents "the first empirical evidence of an interaction between the perception of an action and a higher cognitive process such as processing the meaning of an abstract concept." (p. 51), and consequently, because this evidence comes from the observation of another person, it corroborates the gestural theory for communication (Corballis 2002, 2009; Rizzolatti and Arbib 1998).

This ideomotor account for the link between finger movement and numbers has been tested subsequently with an ideomotor paradigm, which involves learning and a transfer phase. In Badets and Pesenti's study (2011), participants were required during a learning phase to enunciate verbally syllables "KI" and "TI" after the presentation on the screen of these two syllables, respectively. Importantly, the verbal responses triggered in the computer screen a closing or an opening hand movement for the KI and TI, respectively (hand movements were the same as those used by Badets and Pesenti 2010). Consequently, as suggested by the ideomotor theory, the responses KI and TI, after this learning phase, are mainly controlled by the expected perceptual consequences that they aim to generate, that is, the closing and opening movements, respectively. During a subsequent transfer phase, participants were required to respond verbally with KI and TI after the processing of small or large numbers (2 vs. 8). It is notable that such number stimuli were never processed or mentioned during the learning phase. The results reveal that participants were slower to enunciate KI after processing a large number. This finding in the transfer phase suggests the mental anticipation of a closing movement to enunciate the syllables KI slowed down in the processing of an incompatible number stimulus associated with a large magnitude. An ideomotor account for numerical cognition has been replicated in several experiments (Badets et al. 2010, 2013) and represents an excellent example of the recycling of an old inherited action–perception mechanism for the processing of a human invention such as Arabic numbers (see Badets et al. 2016).

## The verbal communication

As suggested by Deacon (2010) on language evolution "Its complexity and organization are like nothing else in biology" (p. 9000). In this section, our goal is not to encompass all this complexity, but only to emphasize that a simple action–perception mechanism could be also at work for such high cognitive skills in human. For this part on language processing, it is important to note that there is only indirect theoretical evidence for the ideomotor account. Clearly, a new perspective in cognitive science should be to highlight the ideomotor account in using language paradigm. This new perspective is presented in the future direction of the present manuscript. However, it is worth noting that such indirect evidence suggests the possible co-evolution of language and foresight.

For Chomsky (2010), spoken language in humans has been well established for 100,000 years. However, as suggested by Corballis (2009, 2013), it is also highly probable that such skilled functions in modern humans have evolved gradually over the past 2 million years with the gesture system. Concerning this gradual evolution of language, a recent theory on spoken language emphasizes the role of action and perception mechanisms. For Pickering and Garrod (2013), language production and comprehension are intimately linked and can be theorized as an action (production)–perception (comprehension) system already described in the ideomotor account (Hommel et al. 2001). In this spirit, Hartsuiker and Pickering (2001) already suggested that, based on the ideomotor mechanism, "Natural language processing involves a tight coupling between action (the production of language) and perception (the comprehension of language)" (p. 887). Clearly, during a dialogue alignment between two people (A and B), there is a common mechanism between the expected perceptual effect of the utterance during the production of this utterance (language production by A) and the expected perceptual effect during the comprehension of this utterance by B (see also Hasson and Frith 2016 for this alignment mechanism and other core mechanisms for social interaction like mutual adaptation or the development of complementary behaviour). This common alignment mechanism represents the common coding between action and perception postulated for the ideomotor theory (Prinz 1997; Schütz-Bosbach and Prinz 2007). Thus, and accordingly with Pickering and Garrod (2013), this common coding has probably been recycled for spoken language.

For Hartsuiker and Pickering (2001), the most important concern in psycholinguistic should be dialogue and not monologue as suggested in the theory for perception of others. This language alignment between two people also could reflect the well-known chameleon effect described in the domain of motor control (Chartrand and Bargh 1999). This effect reveals the tendency of an observer to mimic different motor features (e.g. postures or facial expressions) of another person and can represent a cognitive foundation for social interaction (see Chartrand and Lakin 2013 for a review). For Gallese (2008), such a behavioural effect can be found in their neurophysiological explanation of the discovery of mirror neurons. Adapted for a verbal account, Garrod and Pickering (2004) suggested that language alignment involves different linguistic representations during a dialogue, such as word choice, the sound of the word, grammatical form, or the semantics of utterances.

Interestingly, Pickering and Garrod (2013) also suggested that mirror neurons could represent the neuronal correlate for linguistic alignment between two people. Glenberg and Gallese (2012) propose that "there are speech mirror neurons, that is, neural structures that respond both to heard and observed speech and speech production." (p. 908; see also Gallese 2008 for the neuronal exploitation hypothesis). This theoretical account agrees with the theory proposed by Pickering and Garrod (2013) and with neurophysiological findings of mirror neurons on the language network and its evolution (Arbib 2005a, b). Moreover, Anderson (2010) suggested that some language areas were not dedicated to language per se but to the action–perception mechanism first and foremost. Thus, the Broca area in charge of speech production is also a part of the mirror neuron system (Gallese 2008) and can also therefore be central to different motor mechanisms such as learning or the control of sequential actions (Clerget et al. 2011). Action–perception mechanism has been, from a phylogenetic point of view, recycled for a more elaborate linguistic system (see Glenberg and Gallese 2012; Gallese 2008 for this theory on neuronal exploitation hypothesis).

More evidence for expectations surrounding such mechanism arises from the link between language and music. When a musician plays a piano sonata, there is an action-based mechanism that relates to specific finger movements on the piano and an effect-based mechanism that relates to the musical tones generated by the finger movements. This is a typical action–effect system, which is theorized by the ideomotor account (Keller and Koch 2008). In piano performances, it has been suggested that melodic dimensions (i.e. expected effects) are crucial and relatively independent of hand and finger movements (Palmer and van de Sande 1993; Palmer and Meyer 2000). Additionally, like music, language produces auditory effects that are perceived as semantic features, and accordingly, a strong link has been found in many cultures between composed music and speech rhythms (Huron and Ollen 2003; Neuhoff and Lidji 2014), which are both expected auditory perceptual consequences. In the same vein, Liu et al. (2015) have revealed an impaired speech comprehension in patients with congenital amusia (i.e. a musical disorder described like a neuro-genetic disorder of musical perception and production). Finally, it is well known that when a spoken sentence is heard over and over again, a listener can perceive an illusion during a perceived song (Deutsch et al. 2011). This finding reveals that by repetition, an expected auditory perceptual consequence can be attributed to the domains of language or music. For Falk, Rathcke and Dalla Bella (2014), this speech-to-song transformation reveals an "intriguing perceptual phenomenon potentially useful for examining the relations and mutual influences between music and language in terms of shared cognitive resources or mechanisms" (p. 1503).

To summarize, for non-verbal communications such as the gesture system, the ideomotor mechanism has been recycled to process semantic features shared between two people during goal-directed actions. Behavioural evidence comes from the paradigm that during the observation of an action mimicking the grasp of an object, abstract semantic-like number magnitudes can be automatically created in observers (Badets and Pesenti 2010, 2011). For verbal communication in humans, mirror neurons seem to be involved (Pickering and Garrod 2013), and consequently, language could come from an old inherited function dedicated to the observation of others to understand and regulate social interaction (Corballis 2009, 2013; Gallese 2008). More importantly, it seems that, like music perception and production, language capacity puts a strong emphasis on the expected auditory effect during a dialogue (Huron and Ollen 2003; Neuhoff and Lidji 2014). This crucial role of the expected effect represents, on a behavioural level, the ideomotor recycling mechanism for spoken language.

The next section will present future directions for the ideomotor account in language, the link between tool use and language, and the foresight capacity in non-human animals that, altogether, constitute important perspectives in cognitive sciences.

## Future directions and conclusion

As mentioned in the different parts of the present article, it is obvious that spoken language, foresight capacity and tool use in human animals involve quite separate brain structures and a myriad of cognitive functions associated with different mechanisms. However, as suggested by Badets and Osiurak (2015a), if scholars wish to better understand a possible link between different domains, it is of primary importance to explore and grasp the lowest common denominator among these domains. "Science is not ultimately about explaining the causality of any particular event. Instead, it is about understanding fundamental principles of organization and function" (Wilson 2002; p. 630). Consequently, we suggest that, probably among others, a common denominator between tool use, spoken language, and foresight capacity could be the implication of the ideomotor mechanism.

On the other hand, the reader can realize that empirical evidence linking spoken language, foresight capacity, and tool use is still lacking. Importantly, correlation (an ideomotor account for the three domains) does not mean causality (the emergence of the three domains from a single ideomotor mechanism). However, just claiming from an evolutionary viewpoint that there is a co-evolution of language and foresight throughout tool use (Corballis 2013; Gärdenfors and Osvath 2010) is appealing but lacks of detailed cognitive mechanism in order to assess such hypothesis. Here, we draw attention that an ideomotor mechanism could represent a common denominator between the three domains. This offers new research perspectives from an action–perception mechanism well-identified by researchers since 40 years (Badets and Osiurak 2015b; Koch et al. 2004; Nattkemper et al. 2010; Shin et al. 2010; Waszak et al. 2012). The next paragraphs present possible future directions in relation to important questions for scholars from an ontogenetic and phylogenetic perspective.

As just mentioned, empirical direct evidence for the ideomotor account in language processing is lacking and should constitute an important perspective in cognitive sciences. We would like to suggest that voluntary complex behaviour such as spoken language is organized by way of a representation of expected perceptual events in the environment (see Mechsner et al. 2001, for this claim on motor control). Such anticipated events on action regulation have higher priority than the representation of the movement itself (Badets and Osiurak 2015b; Iacoboni 2009) and can be understood as the behavioural mark of the ideomotor mechanism. Future directions in the language domain should keep in mind this core assumption. For example, in using a bilingual paradigm, it could be interesting to reveal that the first and the second language can be primed by a same expected perceptual effect. Here, both languages represent action regulation devoted to common effects during dialogue. Accordingly, with the use of the action–effect learning paradigm (Elsner and Hommel 2001; Greenwald 1970), such common effects in environment could prime in a same extent different words.

From another ontogenetic perspective, it could be important to explore whether tool use and language emergence during childhood are based on a common expected perceptual mechanism as suggested by the ideomotor recycling theory. Accordingly, Larsson (2015) offered an interesting theory on the link and the evolution of language and tool use. This theory is consistent with the ideomotor theory and the recycling mechanism. For Larson, producing and perceiving sound by tool use can play a crucial role for the emergence of vocal learning abilities. For several millions of years, the sound of tools in the environment has been relevant information for communication and the emergence of language. In the present article, we have developed the potential emergence of communication and language from the observation of others (Corballis 2009; Rizzolatti and Arbib 1998). For Larsson (2015), the sound of tools can have the same potential as visual information for communicative abilities. Accordingly, sounds, that is, the perceptual auditory events in the environment, have a crucial role in the following process: "Pantomimes of transitive gestures involving objects or tool use may constitute a link between tool use and communicative manual actions and therefore may have been essential in the development of human technology and of a gestural language…" (p. 999, Larsson 2015). Clearly, this claim is consistent with the ideomotor theory, which emphasizes the expected perceptual effect for behaviour regulation. Based on these predictions, it could be interesting to assess whether language acquisition and tool use and its associated sound processing can develop in concomitant steps during normal development in humans. Specifically, in using the response–effect compatibility paradigm (Koch and Kunde 2002; Kunde 2001), we could explore whether a same or different compatibility could be observed between spoken word and tool use for a same associated compatible or incompatible sound effect.

From the narrative foresight (Milojevic and Inayatullah 2015), the link between language and foresight can be investigated through narrative paradigm. According to this view, humans have been suggested to possess the ability to mentally simulate future scenarios throughout episodic memory, which addresses personal events (Suddendorf and Corballis 2007). What about for non-human animals? In this present article, we do not deny the existence of an episodic foresight; rather, we shall strive to refine this perspective by presenting an ideomotor account. On a neurophysiological level, the hippocampus might play a key role in this anticipative mechanism (Pfister et al. 2014; see also Melcher et al. 2013 for a hippocampus and parahippocampal gyrus activity in ideomotor paradigm). Corballis (2013) proposed that hippocampal activity may be the neuronal bond between human and non-human animals to sustain the common capacity for foresight. From a phylogenetic perspective, it is worth noting that the ideomotor mechanism is obviously present in non-human animals (Badets et al. 2016; Shin et al. 2010; Stock and Stock 2004, for reviews). Consequently, if this mechanism is important for foresight capacity in humans, as we have posited here, it could be argued that non-human animals could use the same mechanism to envision the future. The ideomotor paradigms developed in this paper (i.e. the action–effect learning paradigm, the response–effect compatibility paradigm, and the action–perception race paradigm) could be used in non-human animals studies in order to explore foresight capacity.

To conclude, we would like to emphasize that the ideomotor mechanism has been recycled and is currently at work for tool use, language, and foresight capacity. This hypothesis identifies a well-known mechanism (i.e. the ideomotor mechanism) for the claim that tool use could be the starting point of the emergence of language and foresight, as already suggested by Corballis (2009, 2013; see also Gärdenfors and Osvath 2010; Plummer 2004). From approximately 2.6 to 1.6 million years ago, the emergence of tool use associated with the auditory and visual events they produce has constituted the prerequisite for communicative abilities among others. Because tools for future use can represent a survival advantage and then constitute the core of prospective cognition in humans (Gärdenfors and Osvath 2010), its link with language acquisition through expected perceptual effects in the environment seems plausible by recycling of a single action–perception mechanism, as suggested by the present ideomotor theory.

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