Sensorimotor Intentionality:
The origins of intentionality in prospective agent action.

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Abstract

Efficient prospective motor control, evident in human activity from birth, reveals an adaptive intentionality of a primary, pre-reflective, and pre-conceptual nature that we identify here as sensorimotor intentionality. We identify a structural continuity between the emergence of this earliest form of prospective movement and the structure of mental states as intentional or content-directed in more advanced forms. We base our proposal on motor control studies, from foetal observations through infancy. These studies reveal movements are guided by anticipations of future effects, even from before birth. This implies that these movements, even if they are simple and discrete, are the *actions* of an intentional agent. We develop this notion to present a theory of the developing organisation of a core feature of cognition as embodied agent action, from early single actions with proximal prospectivity to the complex serial ordering of actions into projects to reach distal goals. We claim the prospective structural continuity from early and simple actions to later complex projects of serially-ordered actions confirms the existence of an ontogenetically primary form of content-directedness that is a driver for learning and development. Its implications for understanding autism are discussed.

Keywords: intentionality, sensorimotor, action, embodied cognition, development, autism

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Introduction

Mental states, such as perceptions involving complex stimuli and memory, beliefs about a social and object world, and desires to engage with these worlds, are necessarily *about* something. They are 'content-directed' or 'intentional'. Intentionality as 'being about something' is a hallmark of mental phenomena (Brentano, 1874; Husserl, 1913; Merleau-Ponty, 1945; Searle, 1983).[1] It constitutes a core structure of mental states that requires investigation by an interdisciplinary study of the human mind. In his discussion of philosophical psychology Franz Brentano (1874) reinvigorated the notion of intentionality as a core feature of mental states, "Every mental phenomena is characterised by… the intentional (or mental) inexistence of an object, and what we might call... reference to a content, direction toward an object... or immanent objectivity." (p. 88).

In this paper, we explore the origins of intentionality as 'being about something' in the development of motor control. We aim to demonstrate that understanding mental phenomena as intentional or referring to content must take into account the development of a pre-reflective bodily intentionality or goal-directedness, identified here as 'primary ' sensorimotor intentionality'. We draw on evidence from studies of the development of human movement to show that sensorimotor behaviour, even from before birth, incorporates an anticipatory structure engaged toward some future consequence, even though such action in early development is not necessarily conceptually or cognitively complex (Lee, 2005; Lee, 2009; Legrand, 2006; Trevarthen, 1984; von Hofsten, 2004; von Hofsten, 2009).

We make two contributions to the interdisciplinary study of intentionality of mental states and the nature of sensorimotor actions. (i) We bring out the anticipatory, goal-directed nature of even the most primitive sensorimotor behaviours and show they are governed by a pre-reflective, pre-conceptual 'sensorimotor intentionality'. (ii) We trace the development of the intentional structure of mental states to development of motor control and thereby ground the study of intentional structure of mental states in the study of ontogenetically primary motor engagement.

Understanding of the role of action in constituting psychological states and in cognitive development has its origins in early psychological study by Baldwin (1895) and Piaget (1953; Piaget, 1954). Their observations of infant limb movement identified an exploratory and sensation-seeking property of even basic actions essential for learning and cognitive development, establishing a non-trivial role of action in development currently widely discussed by a growing body of literature that crosses the disciplinary boundaries of developmental psychology, cognitive science, and philosophy (Clark, 1997; Gallagher, 2005; Gallese, 2005; Gangopadhyay et al., 2010; Grammont et al., 2010; Haggard et al., 2008; Hobson, 2002; Hurley, 1998; Noë, 2004; Pezzulo, 2011; Pezzulo et al., 2008; Reddy, 2008; Reed, 1996; Shapiro, 2011; Thelen and Smith, 1994; Thompson, 2007; von Hofsten, 2004; Woodward and Needham, 2008). A major feature of this new body of work is the emerging approach of embodied cognition advanced in the last two decades to begin to replace a purely functionalist paradigm for the study of the human mind (Noë, 2004; Pezzulo and Castelfranchi, 2009; Sheets-Johnstone, 2011;

Stewart et al., 2011; Thelen and Smith, 1994; Thompson, 2007; Varela et al., 1991; von Hofsten, 2009).

However, more conceptual work is required to uncover the properties and aspects of embodiment which are of critical importance to a study of psychological and cognitive development as embodied phenomena. In particular, though embodied cognition approaches stress that cognition is an embodied *activity* (Noë, 2004; Pezzulo and Castelfranchi, 2009; Sheets-Johnstone, 2011; Thelen and Smith, 1994; Thompson, 2007; Varela et al., 1991; von Hofsten, 2009), and recent models have been proposed to explain motor dynamics and motor contribution to cognition (Pacherie, 2008; Pezzulo and Castelfranchi, 2009; von Hofsten, 2004; Thelen and Smith, 1994), little is discussed by way of fundamental bodily properties that are supposed to seal the gap between mental and physical agency into a unified account of cognition as embodied agent action.

One solution to bridge this divide lies in the intentional nature of mental states and, as we argue here, in its ontogenetic origins in the sensorimotor actions of the body. Thus, we explore evidence that there exists, from the very earliest signs of the integrative actions of the nervous system, a primary sensorimotor intentionality that develops in cognitive sophistication and motor precision during ontogenesis, but remains fundamentally unchanged and continuous throughout life, driving and shaping development, learning, and cognition.[2]

Research on intentionality has a notable history in psychology, but its definition, evidence for its presence, and developmental origins are disputed and require improved understanding (Zeedyk, 1996). A large body of work on infant intentionality works to resolve its emergence in the means-ends relationship between an action and its sensory effects. For instance, Bower, Broughton, and Moore (1970) demonstrated that when a newborn infant's attempt to grab an object was thwarted, in the case of a visual illusion experiment, distress ensued. Similarly, a number of experiments have shown infants adjust the pattern of their kick to elicit action in an overhead mobile and again, if the conditions are manipulated so that no response or minimal response is given, thwarting the infant's expectation, distress ensues (Angulo-Kinzler, 2001; Fagen and Rovee, 1976; Rovee-Collier et al., 1978; Rovee-Collier and Gekoski, 1979). Further studies show neonates will move their arms to achieve a number of particular sensory effects (van der Meer, 1997; van der Meer and van der Weel, 2011; van der Meer et al., 1995). These means-ends demonstrations support the notion of an early infant intentionality or content-directedness that requires an additional sensory effect consequent on, but also above and beyond the simple act of moving. They are tacit object-directed actions.

In this paper we elaborate on a feature of motor control more fundamental to its mechanism and, we argue here, essential for understanding the origins of intentionality: the necessary requirement of its *prospective*, future-oriented organisation (Bernstein, 1967; Lee, 2009; von Hofsten, 1993; von Hofsten, 2004). Our notion of sensorimotor intentionality focuses on the nature of skeletomuscular biomechanics and its underpinning neurophysiological control, which together produce a necessary prospective psychophysical structure. This prospective structure is inherent in an agent's simple sensorimotor dynamic. We claim it contains within it an 'object' of future effect and is necessarily intentional or content-directed, as governed by a *pre-reflective bodily intentionality*, which ontogenetically grounds the content-directed structure of mental states. This primary sensorimotor intentionality is continuous with, but must not to be mistaken for, intentionality of action as directed toward *reflectively and conceptually* formed goal states present, for *e.g.*, in advanced adult cognitive processes. We evidence developmental invariance from pre-reflective sensorimotor intentionality where the object is inherent in its prospective sensorimotor dynamic, to more advanced states of content-directedness where the object has become abstracted from this primary sensorimotor dynamic to achieve cognitively complex content-directedness characteristic of adult intentionality. In his discussion of intentionality, Brentano (1874) states "every mental phenomena includes something as object within itself" (p. 88).[3] Our reasoning suggests this "something as object" is born of the necessity for prospective control.

The following section introduces the notion of sensorimotor intentionality in terms of prospectivity – the idea that control of movement is necessarily geared to the future – in an embodied agent's motoric interactions with the world. It traces the origin and development of prospective control in the sensorimotor actions of the foetus and growing infant, and elaborates on the role of the brain and body in enabling prospective control of sensorimotor activity, and its development. Next, we present a hierarchy of sensorimotor intentionality and discuss the intentional structure of cognitive mechanisms adapted for actions of more elaborate complexity. This is followed by an application of the notion of sensorimotor intentionality for understanding some recent data on motor impairments in autism. We conclude with the implications of our proposal for understanding psychological development of more complex cognition such as memories, plans, and concepts, and their neural organisation, and for future interdisciplinary study.

Sensorimotor Intentionality: Prospectivity in sensorimotor actions

A grounding premise of embodied approaches to cognition is that the experiencing subject is necessarily an agent of physical and mental acts (Clark, 1997; Hurley, 1998; Reed, 1996). Sensory experiences and higher order cognitive states do not just happen to the cognizing subject, they are generated by an embodied agent's active engagement with the experienced world (Gibson, 1966; Noë, 2004). And this active engagement generates physical forces that must fundamentally be integrated across the body and controlled with a view to the future to compensate ahead of time its forces of momentum, even before any additional sensory consequence is considered, as we describe next.

Prospective Sensorimotor Control

An essential property of all animal actions, complex or single, is their *prospectivity* or future directedness (von Hofsten, 2004). Externally oriented animal action carried out through the activities of its skeletomusculature in movements of the limbs, body, and head are rarely just reactive reflex responses, they are an expensive activity of the animal's vital energy resources and neuromotor system that work to move the animal forward in space and time to a new point in experience with a new set of possibilities. And to do this economically and with adaptive effect, they must be guided by prospective perceptual control (von Hofsten, 1993). Even a single simple action, like a rotation of the head, must be guided 'ahead in time' in order that the forces of momenta generated do not over-turn the head, potentially causing damage, and do not under-turn the head, failing to make effective action. Information originating from the muscles and tendons of the neck integrated with the distance senses of sight and hearing enable the agent to move from 'where it is' to 'where it wants to be', situated within an environment of possible action (Lee, 2009; Lee, 2005). Even the spontaneous actions of newborns, repeated over and over again, enable exploration of the action systems of one's developing body, their possibilities, and their consequential effects (Baldwin, 1895; Piaget, 1953).

Simple actions, such as a single displacement from one position to another of the hand or foot, or a turn of the head, are characterised by continuous velocity from one position to the next, produced by a regular pattern of acceleration then deceleration. From their onset, these single units of movement require control with knowledge of their imminent consequences, realised with millisecond precision, in order that the flow of their execution be synergistic –and not counter-productive – with lawful biomechanical forces (Lee, 2005; Lee, 2009; von Hofsten, 1993). Bernstein (1967) recognised this essential feature of animal movement, proposing a 'motor image' was necessary to accommodate the distribution of inertial forces and momenta in a parsimonious manner that required prospective patterning for skilful and effective animal action.

Further, actions in one part of the body generate consequential forces in all other parts of the body. These forces must be coordinated together to achieve efficiency, especially under gravity where unanticipated consequences can upset balance, cause postural failure, and create injury. Thus, actions across the body must be coordinated together, and this can only be achieved by sensorimotor anticipation of their combined effect. The multiplex nature of an animal's body with its articulated motoric skeletomusculature requires a complex and precise coordination for the activities of its parts work in synergy (Trevarthen, 1984; Trevarthen et al., 2011; von Hofsten, 1993; von Hofsten, 2004). This is the principle function of an integrative nervous system. If the individual actions of the body parts were not prospectively guided with integrated anticipation of their combined effects, the animal would be forced to 're-act' to unanticipated inertial forces, forcing the organism into a costly and counter-productive game of compensating and corrective movements. Thus, the self-generated actions of a moving organism are orchestrated prospectively to make use of inevitable biomechanical consequences of action synergistically.

Further, movements require monitoring. There always exists a degree of unpredictability in the imminent future, especially from forces outside of the body, such as a change in wind velocity or the presence of an unseen obstacle. Movements must be perceptually guided so they remain on track even when disturbed. Thus, all single actions of a part of the body, such as a reach of the arm, a kick of the leg, or a turn of the head are perceptually guided with proprioceptive feedback so that the movement stays on course to reach its target. In this way, the effector of action, the foot, hand, or head in these cases, accelerates from rest then decelerates to its goal in one swift and efficient movement made in concert with the other actions of the body. These prospective actions integrated across the body serve the needs of the organism as it supports its mass in balance against gravity.

In sum, prospective sensorimotor control is characterised by the properties of an anticipatory sensorimotor control, prospective sensorimotor integration, and sensorimotor monitoring. When functioning effectively as an integrated, coordinated sensorimotor whole, an animal's or a person's movements exhibit a coherence and synergy that demonstrates a prospectively organised motor coordination and control. Its particular, immediate, and primary sensorimotor intention is a biomechanical necessity in this regard, giving a prospective frame of reference under which to coordinate all skeletomotor action, generating perceptual and motor coherence in the process (Bernstein, 1967; Lee, 1993; von Hofsten, 1991). Without such a so-called 'goal-oriented' cohesion, the animal would otherwise be a cacophony of individual parts.

Prospective sensorimotor control has been extensively researched in empirical studies, especially using paradigms to measure the visuo-motor goal-directed action patterns and their neural organisation in the acquisition of objects (*e.g.* Delafield-Butt et al., 2010; Jeannerod, 1988; Merchant and Georgopoulos, 2006; Thelen and Fisher, 1983; von Hofsten, 1983; von Hofsten, 1991; Witherington, 2005). However, prospective sensorimotor control is not limited to visuomotor action; it can employ all modalities of sense -- sound, touch, and smell being particularly important cues in early life – with their varied spatial and temporal properties (Lee et al., 1995; Lee, 2009). Especially important is proprioceptive control of movements and postural compositions of the body (Witherington et al., 2002). Body-space goals, such as a limb flexion or head rotation, are achieved within a spatial, dynamic awareness of the body without the need for external reference. The impulse for self-generated movement simultaneously anticipates its proprioceptive and exteroceptive sensory effects by *reafferent feedback*, enabling maintenance of an integrated neuromotor self and differentiation of oneself from the environment (Sperry, 1950; von Holst & Mittelstaedt, 1950).

Situated amongst environmental features, these self-generated movements may be coupled to senses of events arising from the distance receptors (Lee, 1978). For example, a rotation of the head may be made within its own frame of reference, or in orientation to an external event sensed in sight, smell, hearing, and touch. This multimodal exteroceptive information integrated with anticipatory reafference gives a body-environment system for perception-in-action that adjusts the musculatures of the body for engagement with external objects, altogether made in prospectively coordinated coherence. Thus, proprioceptive information from senses of the muscles, tendons, and points of articulation with its associated reafference forms the foundation for self-generated body movement, and ex-proprioceptive information made available from the organs of sight, touch, hearing, and smell give additional data on the frame of action. Together with exteroceptive sense of environmental objects and events, these sensorimotor dimensions establish the sense of relation of an agentive self situated motorically and dynamically within environmental features (Lee, 1978; Lee 1993; Sherrington, 1947; Sperry, 1950; von Holst & Mittelstaedt, 1950).

The nature of the information employed in prospective animal sensorimotor control is under considerable examination. Interestingly, prospectively controlled movements have received precise mathematical description by a particular sensorimotor control theory, 'general tau theory', which identifies a sensorimotor informational variable hinged on the acquisition of future states (Lee, 1976; Lee, 2009; Pepping and Grealy, 2007). Tau theory posits organisms principally perceive and control so-called 'action-gaps' – gaps between present experience and a desired future one – by means of a directly perceptible informational variable, tau (τ). τ is defined by the relative rate of change of the action-gap, and by employing a number of simple strategies to maintain tau derivative values or by coupling two or more sensory tau values together, the organism may acquire goal states parsimoniously with little computational load (Lee, 1980; Lee et al., 1999). The fact that the tau variable is structured by the goal relieves the nervous system from otherwise complex predictive sensorimotor calculations and provides a unique informational variable that can be directly sensed and controlled.

τ information only exists in relation to future states and is therefore prospective information by definition.[4] Evidence indicates this particular form of prospective sensorimotor control structures goal-directed actions made by a large variety of organisms, including birds, bats, and bees, as well as goal-directed human action (reviewed in Lee, 2009). τ information may be a universal sensorimotor variable evolved with the origins of animal motility (Delafield-Butt et al., 2012; Delafield-Butt and Schögler, 2007), and its deployment in human sensorimotor control may afford a measured indicator of the degree of prospectivity in an action – those actions that statistically agree with the theory can be considered prospectively organised. General tau theory gives us the benefit of explicit frames of sensorimotor action made in terms of goal-oriented control, and gives evidence of the necessity of prospectivity in animal action.

Origins and Early Development of Prospective Sensorimotor Control in Humans

From the beginning of life post-partum, the infant's engagement with the world depends on its capacity for prospectively controlling sensorimotor activity, and this capacity increases rapidly over the first months with improved goal-directed motor coordination of tasks such as reach-to-grasp and standing (von Hofsten, 2004; von Hofsten, 2005). More complex tasks requiring serial ordering of several actions, such as manual manipulation of objects, begins to develop significantly only once upright posture is established at about ten months (Trevarthen, 1986), and expands in capacity throughout early childhood as memory and action planning begin to enable abstract reasoning (Piaget, 1954), but their prospective orientation is a feature that remains invariant, no matter their degree of immediacy or complexity.

The degree of capacity for complex action is dependent on the individual's capacity for prospective planning and control, and this begins simply in early life. For example, at birth human infants have relatively poor visuo-motor coupling and the scope and accuracy of their visually-guided movements to reach to objects is limited, but by seven months of age they are able to direct the movement of their hand to objects of interest with skill and accuracy (von Hofsten, 1991; von Hofsten and Ronnqvist, 1993). Similarly, from the onset of upright posture at about ten months, as they learn to stand or to manipulate objects, the inertial forces and momenta of the body's actions are anticipated and controlled for with increasing precision (Barela et al., 1999; Witherington et al., 2002). Prospective control of tasks with increasing sophistication is acquired in human development and refined through learning. However, data prove that the foundation of prospective awareness and control of the sensory effects of moving are established much earlier in development, evident in the simplest actions of the embryo and foetus well before birth.

The first movements of a new human organism occur toward the end of embryogenesis, in the seventh gestational week (reviewed in Einspieler, Prayer, & Prechtl, 2012). These movements first identified by abdominal ultrasound are spontaneous, self-generated movements only just discernible in the small embryo (*ca.* 2 cm in length) (Ianniruberto & Tajani, 1981; de Vries et al., 1982; van Doungen & Goudie, 1980; Goto & Kato, 1983; Prechtl, 1985, 1986). Improved high resolution transvaginal ultrasound observation clarify these first movements consist of small, sideways bending of the head or rump both and begin at precisely 7 weeks 2 days gestational age (Lüchinger et al., 2008). A few days later and slow, small stereotyped movements of the trunk with a little activity in the arms and legs become apparent. And by 8 weeks so-called ‘general movements’ comprising rotations and displacements of the thorax, partial rotations of the head, and rotation and displacements of the limbs rotation are patent (de Vries et al., 1982; Piontelli, 2006; Lüchinger et al., 2008). All of these very simple, very early movements generate biomechanical forces of inertia and momentum not only in the limb, head, trunk, or rump most in motion, but across the whole body through opposite reciprocal force, giving opportunity for neuromotor learning whole organism consequences of action. This first generation of experiential knowledge can be later incorporated into subsequent motor acts for whole body prospective coordination and control. This establishes an embodied foundation for further learning the specific sensory consequences arising from external forces by external ‘objects’, and the process of learning from prospective action – through a developing sensorimotor intentionality – is begun.

Movement in late embryogenesis and foetal growth is important for developmental health, especially – as demonstrated in studies of chick – for tuning the neuromotor system through regulation of programmed cell death (Usiak and Landmesser, 1999; Oppenheim et al 2003) motor endplate formation (Benoit and Changeux, 1975), and normal distribution of neurotransmitter receptors on muscle fibres, pattern of neuromuscular synaptic contacts, and population of spinal motor neurons (Purves and Lichtman, 1980; Harris, 1981). Movement is also required for normal organogenesis, generating mechanical tensions and forces that preserve tissue integrity, for *e.g.* by preventing adhesion (Visser and Prechtl 1988) as well as possible epigenetic regulations (Inanlou et al 2005). Its failure in human foetal growth can be lethal (Hall, 2009).

Thus, these early movements serve important psychobiological mechanisms adjusting both tissue growth and neural connectivity. Their experienced action pattern and sensed response appears to confirm a continuum of agency specific to that individual. For example, Piontelli reported idiosyncratic behavioural consistencies from foetal to childhood life (Piontelli, 1992; 2002) and Beckoff noted a functional continuity between foetal ‘play’ and childhood play (Beckoff et al 1980). Oppenheim (1981a) reasons foetal action is both functional and adaptive, and Winn (2012) notes behavioural learning is evident in brainstem.

Soon after the earliest onset of movement, at eight to ten weeks gestational age, foetal arm movements are directed to parts of the body, especially to the face and head (Piontelli, 2010). These movements are first associated with general movements and over gestational weeks ten to fourteen quickly become differentiated into individual, isolate actions with increasing goal-direction to parts of the body (*ibid*, pp. 60). At fourteen weeks gestational age, quantified kinematic analyses reveal differentiation of motor planning evident in the action pattern of the movement structured by its final position, or ‘goal’ (Castiello et al., 2010). In the case of twin pregnancies, special twin-directed movements are operational by eighteen weeks gestational age, indicative of a primary ‘social awareness’ (*ibid.*), and in singleton pregnancies kinematic studies confirm motor planning is operational by twenty-two weeks gestational age (Zoia et al., 2007).

Detailed observational studies of foetal behaviour using real-time ultrasonography also demonstrate an exploratory sensation-testing nature of foetal action from as early as ten weeks gestational age. At this stage of development, some areas of the body are innervated with sensory nerve fibres and others are not. Those that are innervated, such as the lips, cheeks, ears, and parietal bone are frequently touched by the hands, the fingers of which are themselves richly innervated. These touches to sensitive innervated regions create an autostimulatory feed-back loop, where the action creates contact between the fingers and head, giving simultaneously a proprioceptive response in the resistance met at contact, the sensation of touch in the fingers, and the sensation of touch in the innervated region. Foetuses have been observed exploring the boundary of the innervated and uninnervated regions, particularly at the anterior fontanel of the forehead where innervation ceases. As the nervous innervation of the forehead increases and the boundary migrates during development, so the foetus' exploration of this region migrates with the boundary, demonstrating the foetus was not merely exploring a spatial region, but the special relationship between differences in autostimulatory feed-back either side of the boundary of innervation (Piontelli, 2010, pp. 61-67).

The development of foetal movements in the second trimester shows an increase in prospective control and sensorimotor anticipation. For example, from 19 weeks gestational age, 4D ultrasound data demonstrate anticipatory mouth opening during hand movements directed there, suggesting intersensorimotor anticipatory coupling (Myowa-Yamakoshi & Takeshita, 2006). Prospective control of the limbs and hands and the ability to programme coordinated whole-body movements also increases. For example, feats such as a 'bicycling' the legs, turning the body over and around in the womb, reaching to touch the placental lining, umbilical cord, twin foetus, or parts of one's own body (de Vries et al., 1982; Piontelli, 2010; Piontelli, 1992), all indicate that foetal motor actions are enacted with a degree of precision that require coordinated prospective control.

At birth, more detailed kinematic measurements become possible. Micro-analytic descriptions show that limb movements and head and eye movements of newborns are coordinated within the body and may be directed to locate objects external to the body (Trevarthen, 1984). Measurement of the control of sucking by newborn infants show that prospective information is used to regulate the intra-oral pressure that directs the flow of milk whilst feeding (Craig and Lee, 1999), and that this degree of skill in the prospective control of the suck may be used as an indication of neurological integrity (Craig et al., 2000). Newborn infants in a dark room direct their arm movements to keep the arm visible in a light beam (van der Meer, 1997) and when disturbed by experimental conditions, they compensate the strength in the movement to counteract an imposed weight (van der Meer et al., 1995; van der Meer et al., 1996). Newborn infants can also direct their movements with awareness of the location of sounds outside their bodies. Alegria and Noirot (1978) demonstrated sensitive orientation and searching in response to the mother's voice within hours after birth, and infants two to six weeks of age may guide their arm and body movements to hear their mother's speech by moving speakers attached to their left or right wrists towards their ear (van der Meer and van der Weel, 2011).

Further studies demonstrate that the infant's sensorimotor engagement with the world is characterised by exploration and repetition of a desired sensory effect, an agency that explores new action consequences and that learns to structure motor control to achieve desired effects in what Baldwin (1895) first identified as 'circular reactions'. For example, four month old infants adjust their spontaneous kicking patterns when certain patterns are geared to move an entertaining mobile (Chen et al., 2002), demonstrating that the kicks are adjusted to generate a particular sensory effect. These studies and many others beside (Angulo-Kinzler, 2001; Fagen and Rovee, 1976; Butterworth and Hopkins, 1988; Frye et al., 1983; Lewis et al., 1990; Rovee-Collier et al., 1978; Rovee-Collier and Gekoski, 1979; Rovee-Collier and Sullivan, 1980; Thelen and Fisher, 1983; Tomasello and Carpenter, 2007; Trevarthen, 1986) contribute to a growing body of literature that attends to the importance of pre-conceptual goal-directedness for learning and development (Adolf et al., 2010; Frye, 1991; Hobson, 2002; Iversen, 2010; Reddy, 2008; Sheets-Johnstone, 2011; Stern, 2010; Stewart et al., 2011; Thelen, 1989; Trevarthen & Delafield-Butt, 2013a).

The exploratory perception-action cycles that uncover these sensory effects – active from before birth – not only enable the emergence of meaningful experiential content, but also ground the individual's developing knowledge of how the environment responds to its demands for interaction (Piaget, 1953; Piaget, 1954). Borrowing from Piaget, these cycles of action and response allow formation of predictable sensorimotor consequences that, with each repetition, accommodate new and unexpected demands. Through iterative cycles circular reactions (Baldwin, 1895), conceptual knowledge enabling abstract thought is built (Piaget, 1954).[5] This ontogenetically primary cycle of embodied sensorimotor action situated within an environment shapes the cognitive processes dealing with an increasing complexity of information as perceptual, motor, memory, and planning systems mature. Thus, knowledge of the world is necessarily embodied, structured by an awareness of how experience unfolds within the actions of a primary and pre-reflective sensorimotor intentionality.

In sum, there exists a basic prospective control of movement fundamental to acquisition of skilled purposeful action that develops well before birth and that is available to master environmental responses. The anticipatory nature of motor engagement enables and sustains the emergence of meaning of an embodied self in a responsive world. Thus, the notion of sensorimotor intentionality we advance identifies this prospective and psychophysical (psychomotor) foundation of cognitive agency; it identifies a discreet expression of *mind-body unity* – not mind-body duality – enacted and sustained through neuromotor physiology. We stress this foundation of self-generated experience is necessary for understanding cognition, which, as Piaget accepted from the beginning, is embodied agent action. Mental experience is necessarily grounded in the structure of sensorimotor intentionality as it engages with "the potentiality of a certain world." (Merleau-Ponty, 2002, p. 122).

Expansion of Prospective Sensorimotor Control and Sensorimotor Intentionality

The primary ontogenetic expression of sensorimotor intentionality is characterised by its basic prospective character, with or without consequential sensory feedback from external or other body part objects. All experience through movement is founded on this basic requirement for anticipation of biomechanical forces generated in movement and requiring control. It engenders the first form of prospective awareness and is enacted through prospective integration of muscular forces across the organism – a predominantly proprioceptive sensorimotor integration. Additional anticipation of sensory consequences of an action from the exteroceptive senses enable further focus and learning of contingencies, even *in utero*. Thus, primary sensorimotor intentionality includes a basic prospective awareness of the proprioceptive and/or exteroceptive consequences of action.

In development, sensorimotor knowledge continues to expand to include within it consequential *affordances* for further action at the end of an imminent one, enabling potential for chaining a second future action beyond the first. Development of 'projects' of serially organised actions to achieve distal goals marks the transition from a *primary* to a *secondary* sensorimotor intentionality (see below). For example, neonates exhibit coordinated control of arm gesture that may be focussed in so-called 'pre-reaching' movement – movement generated with coordination of musculatures across the body, including head orientation, eye gaze, whole body and hind-limb posture (Trevarthen, 1984; von Hofsten, 1984). These pre-reaching movements may or may not be directed toward external objects, but their control and coordination requires a prospective sensorimotor integration that indicates a pre-reflexive, pre-conceptual intentionality generates its focal coherence. By four and a half months, infants may reach to objects with improved precision, indicating development of greater focal precision of self-environment sensorimotor coupling, though at this point there is no indication of further anticipatory knowledge: there is no adjustment to hand posture to accommodate the target object. In other words, the infant has not yet integrated (*c.f.* assimilated) the subsequent affordance for further action when reaching the object. It is only from four and a half to five months that there is indication, however rudimentary, of prospective sensorimotor knowledge of what could come after this initial intention-action: hand orientation adjustments are made at *initiation* of the reach to grasp to accommodate the object (von Hofsten and Fazel-Zandy, 1984; Wentworth et al., 2000). Thus, the degree of infant prospectivity expands from mere prospective control of action (without prospective motor assimilation of its consequences) in the pre-reach and early reach before four and a half months, to one that takes into account its consequent affordances for action from the action outset.

In this way, sensorimotor intentions expand in reach to include further and farther future consequences in their prospective motor knowledge resulting in an expansion of cognition and conscious awareness (Pezzulo 2011). Thus, while there may be debate within the literature on mechanisms of learning such improved anticipations, for *e.g.* in mechanisms of grasp learning between five and seven months (Lockman et al., 1984; McCarty et al., 2001; Witherington, 2005), it is clear that action is organised by its future effects – be they oriented to a physical target or not – from the very earliest simple actions of the integrated and agentive organism.

Thus, motor skill retains a core prospectivity that develops in sophistication from simple proprioceptive prospectivity first manifest *in utero*, such as moving the arm or legs, and that begin to include goals of external consequence, such as to touch parts of the body or to touch locations in its immediate environment, to more sophisticated forms of control especially post-natally involving inclusion of broader and more detailed sensory consequences with improved perceptual awareness, giving more accurate visuo-motor and auditory coupling, new proprioceptive compensations under gravity for whole body postural integrations, and detailed focus on aspects of the environment giving expanded perceptual awareness. Over development, we see the 'object' of action becomes slowly abstracted from its prospective immediacy in movement to include more and more distal consequences, but the prospective nature of the object in intention remains invariant.

Neural Substratum for Sensorimotor Intentionality and Primary Conscious Experience

It appears from ultrasound observational data above that directed sensorimotor control enacting a specific intentionality arises quickly *in utero* within the transition from the emergence of the first movements in embryogenesis to early foetal life at fourteen weeks gestation. At the earliest point at seven weeks, the cervical spinal cord nuclei are rapidly forming axodendritic synapses, initially between interneurons and motor neurons, then between afferent fibers and interneurons. The 'special visceral nuclei' of the brain are formed and becoming innervated by integrative emotional systems (Trevarthen, 1985).

The onset of early signs of sensorimotor control at eight weeks gestational age and their confirmation of prospective control in measured kinematics of movement at fourteen weeks suggest the cardinal system for prospectivity is not cortically-mediated sensory learning, but is already a capacity of more primitive neural motor systems. At eight weeks gestational age, when the first performance of controlled isolate limb movements is observed, there is sufficient appendicular skeletomusculature with sensory and motor nervous connectivity to the spinal column and brain stem nuclei for basic proprioceptive motor control (Okado, 1980), but the forebrain is still not well developed, the neocortex is not yet organised (Larroche, 1981) and thalamocortical projections are still immature (Hevner, 2000). Corticospinal projections do not reach the cervical spinal cord until twenty-four weeks gestation (Eyre et al, 2000). This implies that spinal column, brain stem, and midbrain, where connectivity to limb musculature is already established, must be responsible for these first prospectively controlled actions of the limbs.

These phylogenetically ancient brain structures, well-known for visceral organ regulation and sensory and motor information transmission, are not simple relays along the corticospinal tract sending sensory information from inferior visceral and somatic receptors to superior cortical function where mental operation generates motor commands for transmission back through brain stem for skeletal muscle movement. Rather, brain stem complexity, capacity for integration of information, decision-making, learning and memory has become substantiated though a recent and growing body of literature, based on clinical and comparative neurology, neuroscience, and neuropsychology, to present a new perspective of brain stem function that recognises its capacity for these so-called higher cognitive functions and its importance as a core generator of conscious agency (Merker, 2007; Northoff and Panksepp, 2008; Panksepp and Northoff, 2009; Winn, 2012).

Brain stem territories include the necessary functional characteristics for enabling a primary form of consciousness as 'acting with knowing' – an embodied and prospective agentive experience. Somatotopic mapping giving access to *proprioceptive* body-space and tactile information is preserved in brain stem (Marx et al., 2005), distance receptor projections from eyes, ears, and nose laminate in the roof of midbrain giving *exteroceptive* sensory information, and visceral organ function is monitored, especially in periaqueductal grey giving *visceroceptive* information on the body's vital well-being and physiological need. Further, timing mechanisms for sensorimotor control relay with hindbrain cortices for coordination of voluntary skeletomuscular control. Merker (2007) proposes that a brain stem "selection triangle" between action selection, target selection, and motivational ranking based on the needs of the body is a lynchpin of primary conscious experience.

The importance of brain stem conscious control of action was first recognised by neurologists Penfield and Jasper (1954) who observed cortical removal even as radical as hemispherectomy, while resulting in losses of certain forms of information processing or discriminative abilities, did not deprive a patient of all conscious experiential content (*ibid*, p. 477). They were impressed by the extent to which the cortex could be subject to insult without so much as an interruption in the continuity of conscious experience in general. Anencephalic or hydranencephalic children, who do not possess cerebral cortices, but have intact brain stems, can live for many years and enjoy a rich social and emotional life with coordinated, purposeful use of their limbs for communication and mobility. These children are conscious, have feelings, and act with intentions, though their cognitive capacities are greatly reduced (Merker, 2007; Shewmon et al., 1999; Solms and Panksepp, 2012). A comparable situation is found in surgically decerebrated cats and rats that are able to locomote over tricky terrain, perform goal-directed sensorimotor tasks, copulate, and wean litters (Wood, 1964).

Our account of a developing sensorimotor intentionality as rooted in simple prospective action and further enabled by reference to sensorimotor contingency aligns with the centrencephalic theory of consciousness that proposes the functional role of conscious experience is to integrate sensory information for selecting and guiding motor action; the upper brainstem and midbrain regions are identified as the 'core central control system' responsible for this action selection and integrated goal-directed control (Merker, 2007; Northoff and Panksepp, 2008; Panksepp and Northoff, 2009). This integration of information across visceroceptive, proprioceptive, and exteroceptive domains for direction of agency mediates endogenous motives and whole-body motor coordination for action within perception of environmental affordances. Its principle neural substratum, integrating unfolding spatiotemporal frames for body movement, is located within the midbrain tectum, especially the superior colliculus, with the nuclei extending ventrally to the hypothalamus, including the midbrain reticular formation, ventral thalamus, periaqueductal gray, ventral tegmentum and substantia nigra (Merker, 2007). These, with associated 'locomotor centres' constitute the basic mechanism serving navigation. We recall that, in the light of his comparative studies of the vertebrate brain, Coghill (1929) had named midbrain the 'head ganglion of the motor system'. This action-oriented view presenting brain stem as *functionally supra-cortical* though *anatomically sub-cortical* in enabling conscious experience, entails a dramatic rearrangement of priorities in relation to what cognitive neuroscience typically prescribes. It stands in agreement with *Cambridge Declaration on Consciousness* that emphasises evolutionary conservation of core neurophysiological "substrates of conscious states along with *the capacity to exhibit intentional behaviours*" [italics added] (Low, 2012). It is in keeping with our report on the origins of spontaneous prospective sensorimotor control early in development, locating the integrative neural substratum of conscious experience at the interface of a bodily self-awareness (visceral and proprioceptive senses) and environment-awareness (exteroceptive senses).

In our account, then, the cerebral cortex should not be regarded as the locus for a primary form of goal-directed control of bodily movements, but as a further development to elaborate on experience from the primary conscious function of engaging prospectively with the immediacy of the world. As development proceeds, cortical regions become increasingly important contributors giving new cognitive capacities to the agent for 'abstraction' or disengaging from immediately perceived environmental affordances and engaging with (new) cortically-generated ones, *c.f.* 'objects', by forming beliefs, plans, and conceptual understanding of the world. Cortex together with central limbic structures enable expanded action plans that draw on previous experience. The more advanced the level of development and cortical maturation, the more integration of different brain processes becomes involved (Vandekerckhove and Panksepp, 2011). Thus, cortical development over the first years of a child's life marks a shift from an early primary consciousness experience to one constituting cortical abstractions, complex evaluations, and sophisticated planning and control.

Early perception-action cycles composed of simple single goal-directed actions, such as a kick of the leg or reach of the arm, give meaningful proximal content. As cognitive cortical processes dealing with increasing quantity and complexity of information mature, sensory knowledge of these simple action contingencies and their consequent effect for future action are expanded. Meaningful experiential content thus expands beyond the immediate present framed by a simple action to include possible further future actions and their effects subsequent to the proximal one. Further future effects beyond the single action can only be reached through the *serial organisation* of simple single actions into complexes or projects that incorporate a number of actions and their effects. Together with improving memory and capacity for fine motor manipulation, knowledge of the world is generated and refined through serially organising motor experience driven first by basic, and then more complex sensorimotor intention.

An infant's intelligence depends on anticipation of the consequences of an action or serially organised project of actions. Abstract intelligence involving complex memories and plans can anticipate more complex and distant futures. In terms of motor logic, the problem of serial organisation is the problem of serial assembly of single action units that each deliver sensory consequences with new sets of action affordances. Developing knowledge of these and capacity to organise simple action units into projects with greater distal reach expands sensorimotor intelligence to guide the action in the present moment for future gain. Thus, sensorimotor intentions are at first simple and proximal, and later become complex with greater distal purpose.

Any intelligence, no matter how well developed, abstract, and imaginative, must always be fed back through a motor logic to generate its effect in the world. Sperry (1952) reminds us "the sole product of brain function is motor coordination" (p. 297). And it is in the serial organisation of motor acts that intentions and intelligences are developed and expressed, "… all skilled acts seem to involve the same problems of serial ordering, even down to the temporal coordination of muscular contractions in such a movement as reaching and grasping. Analysis of the nervous mechanisms underlying order in the more primitive acts may contribute ultimately to the solution even of the physiology of logic" (Lashley, 1951).

Increasing cortical dominance over the first years of human development marks a shift from proximal sensorimotor projects to ones capable of imagining distal consequences of a series of actions. This generates a development from primary sensorimotor 'intentions in action' to abstract conceptually oriented 'intention to act' (*c.f.* Searle, 1983; Panksepp, 2011). Decision-making, at first brain stem mediated (Merker, 2007; Winn, 2012), comes to be driven by so-called executive prefrontal cortex as it comes to the foreground of conscious reasoning for higher-order selection of distally-oriented prospective action plans (Pezzulo and Castelfranchi, 2009; Vandekerckhove and Panksepp, 2011).

In sum, it appears the locus of primary sensorimotor intentionality integration is upper brain stem initiating, sensing, and controlling the actions of the body's musculature from the spread of nervous connectivity. Our discussion of sensorimotor prospectivity reveals that this primary form of embodied intentionality is ingrained in the integrative activity of the *whole body* from its first coherent expressions in early ontogenesis. One's earliest experience is thus a primary form of 'acting with knowing', and it is through acting that further knowing elaborates and develops. One's earliest conscious experience is thus ingrained in embodied interactions with the world, generating meaningful content for the embodied cognizer by generation and coherence of perception and action (Gallese and Sinigaglia, 2010; Hohwy, 2007; Legrand, 2006) subcortically prospectively organised (Merker, 2007; Northoff and Panksepp, 2008; Panksepp and Northoff, 2009; Vandekerckhove and Panksepp, 2009).

It is important to note the proprioceptive and tactile nature of this earliest foetal consciousness. The special sense organs, having attained their basic function-specific form in the late embryo, are cut off from stimulation by morphological changes in the early fetal period (Hamilton et al., 1962; Trevarthen, 1985). While a self-regulating mobility is clearly functioning, the organs that will explore the rich variety of experiences after birth have reduced function. At 7 1/2 weeks the eyelids grow over the cornea to fuse and reopen again at six months. The ear ossicles develop within a spongy mesoderm and remain blocked to transmission until the last foetal months. The nostrils are closed by epithelial plugs until the last trimester. This leaves a predominantly proprioceptive and tactile world within which the first and second trimester foetus develops. Sensorimotor experience within this small, proximal action-space offers limited structure for developing plans with distal goals. From this early origin, postnatal experience expands to include developing discreet visual and auditory sensing of objects and environments, especially social others, and an emerging capacity of knowing the distal contingencies of an action or serial sequence of actions.

In the following section we elaborate the nature of sensorimotor intentionality and propose a model of its hierarchical organisation. We then discuss the nature of cognitive processes within a framework that views the development of cognition as essentially grounded in a purposeful agent's embodied interaction with the world.

The Roots of Cognition in Sensorimotor Intentionality

The goal states that structure sensorimotor activity accordingly embody the earliest form of cognitive structure, or psychological process, which develop in continuity with basic sensorimotor actions guided by sensorimotor intentionality. Understanding the goal-directed nature of the most basic sensorimotor activities is thus a key to understanding the nature of cognitive processes in more elaborate agent-environment interactions (von Hofsten, 2009). How ontogenetically primary identifiable processes of information organisation emerges primarily in relation to the goal states of the organism is best illustrated by an appreciation of the role of goals in a conscious system. In such a system goals play a varied regulatory role. For example, as Pezzulo and Castlefranchi (2009) observe, goals play motivational, evaluative and prescriptive roles in agent-environment interactions.

Again, noting the role of cognitive appreciation of external conditions in the control of primary motor processes, Jeannerod (1988) writes, “Apparently, even the most elementary motor processes can be influenced (or ‘penetrated’) by specific cognitive states such as expectation, goal, or knowledge of the result. This notion of ‘cognitive penetrability’ (Pylyshyn, 1980) suggests that the neural motor network… might not be totally reducible to its own physical (anatomical and neurophysiological) properties.” (p. 3-4)

As the organism develops complex cognitive capacities, some of its goals become abstract and not tied to ongoing sensorimotor activity within immediate experience. But such abstraction does not entail suspension of the dialogue between the lowest, primary level of sensorimotor intentionality and higher order cognitive processes involved in enabling and enacting goal-directed actions. It does not imply that higher-order, abstracted goal-directed cognitions are parsed into a self-sufficient ‘mental’ higher-order intentional component causally preceding and commanding a mechanical performance of the physical action of the body. Rather, the intentionality or reference to content in goal-directed activities is secured by both bottom-up and top-down prospectivity.[6] We illustrate this in Figure 1 and give detailed consideration of the bi-directional inter-penetrability of intentionality below. Moreover, the cognitive processes enabling top-down control in the form of complex mental states are best described as originating from and sharing the properties of sensorimotor intentionality or an ontogenetically primary and pre-reflective bodily intentionality.

Our model elaborates the structure of goal-directed bodily activities as serially organised into purposive ‘action-chains’ structured by multiple levels of sensorimotor intentionality to propose an account of the emergence of intentional structure of complex cognitive processes governing agent action. We discuss how our proposal of grounding development of cognition in primary sensorimotor intentionality enables an account of the mind and nature of cognitive mechanisms underlying mental states as necessarily grounded in sensorimotor goals and their spatiotemporal frames of reference, rather than as described within a Cartesian mechanistic framework.[7] Intentionality or the object-directed nature of mental states is secured by the successful continuation of the structure of sensorimotor intentionality in higher cognitive processes. Sensorimotor intentions give the framework of an embodied mind, from simple motor activity to abstract thought.

Units of Sensorimotor Intentionality

Skilful engagement with the world is composed of discreet movements that combine serially to give efficient flow and continuity of purpose (Lashley, 1951). Each individual, discreet movement serves a basic task to bring the person one step forward to a new set of relations with the environment. These skeletomuscular movements, governed by the voluntary nervous system, are composed of single ‘action units’. Each action unit accelerates to a peak velocity and then decelerates to its new position. For example, displacements of the fore- or hind-limbs to perform tasks such as reaching or walking are woven together to give efficient and fluid movement, but are constructed by singular units of action each with an acceleration and deceleration to its new position (Lee, 2009). Borrowing from the motor control studies of Fogassi (2005), Lee (2009), and others (Schmidt and Lee, 2011, pp. 266-269; Schneider and Schmidt, 1995; von Hofsten, 1991), we draw out the term 'action unit' to define a displacement of a body part by its continuous velocity toward a goal. For example, reaching for an object, lifting the foot up, turning the head, and so on are singular action units with constant velocity to a new rest position, and it is on the basis of these units that we begin to better uncover the nature of a pre-reflective, pre-conceptual bodily form of goal-directedness or sensorimotor intentionality.

Action units typically take place within one second and always within one and a half seconds (*ibid.*), a time too brief for characterising them as regulated by a reflective control. Thus, while voluntary actions are often described as paradigmatic cases of goal-directed engagement, because they are preceded by reflective, conceptually-formed plans, the goal-directedness of action units that make up these actions are often considered at best derivative as part of wider action controlled by reflective planning. In contrast, we propose that action units are necessarily guided by a form of pre-reflective bodily intentionality or goal-directedness inherent in the *prospective* nature of their control. Such a form of pre-reflective bodily intentionality is necessarily ontogenetically primary to reflective planning, it exists before it and gives the foundation in development for the basic structure of intentional, object-directed mental states that develop over the first years of life.

In development, single sub-second action units (such as a reach) are composed into coherent series with multiple actions to perform complex tasks with distal goals (such as a reach, grasp, and placement). Eating a morsel of food requires moving the hand forward to the morsel, grasping the morsel, moving the hand to mouth, and then chewing the morsel before swallowing it. Each act of the skeletomusculature – each limb displacement, digit displacement, and serial masticulatory displacement – is itself an action unit that takes place typically in less than one second, yet the entire serially-ordered ensemble may take seconds to perform. Such serial organisation requires 'action chaining' into projects of action units (*e.g.* Fogassi et al., 2005) and is not prevalent until after nine months of age. Yet even at birth the infant is able to coordinate whole body movement to orient to an object of interest and the basic form of reach, the pre-reach, is already established (Trevarthen, 1984). Moreover, the movements of the arm are, though basic at first, goal-directed (van der Meer et al., 1995) and their degree of goal-directed, prospective control improves over time (von Hofsten, 1991; von Hofsten and Fazel-Zandy, 1984).

Each individual action unit and each combination of action units must be performed and organised to satisfy the task at hand. Each single action unit must be 'prospectively controlled', because their enactment must take into account their consequential future-oriented trajectory and its subsequent relations with successive acts. In this section we develop the hierarchy of its organisation from basic actions units to complex projects of actions units.

Hierarchy of Sensorimotor Intentionality

To propose an account of how the content-directed or intentional structure of complex cognitive processes governing agent-environment interactions arises from the basic structural properties of an ontogenetically primitive bodily intentionality, we present a model for the organisation of sensorimotor intentionality. We base it on Powers' hierarchy of control loops (Powers, 1973b; Powers, 1973a), which offers a schema for the organisation of animal sensorimotor control and which has been a lynchpin for motor control studies since its first publication. However, it has not been cast in terms of prospective sensorimotor control and the primacy of a sensorimotor intentionality inherent in controlled actions. This re-casting requires a 'temporalization' of the original network model, and we begin to do that re-casting here. This grounds the system in an agent-focussed perspective that acknowledges not only the significance of goal-directedness in basic sensorimotor control processes, but the importance of a hierarchy of motor intentionalities in infant cognitive development. Our model establishes a foundation for psychomotor organisation of a richly reflexive, conceptually-backed adult intentionality (*e.g.* Pacherie, 2008) in developmental sensorimotor origins.

Elaboration of simple goals into more complex, distal, and conceptually rich goal states requires coordination and planning of many movements of many parts of the animal through spatiotemporally longer and more complex projects. Enhanced mobility requires enhanced conscious content (Merker, 2005). Thus, development expands the intentional capacity of a human agent from its fundamental building blocks in individual sensorimotor actions to larger compositions of these to serve goals that extend further into the future 'action space' than single actions do (Pezzulo and Castelfranchi, 2009). These distally-oriented 'projects' of serially organised actions reveal an embedded organisation of goal-directedness in agent-environment interactions. For example, we describe the goal to eat dinner as follows (Figure 1).

To acquire the projected goal of eating dinner (3°), one must make a number of serially organised projects of eating morsels of food (2°). These projects must, in turn, be made of a series of basic sensorimotor action units (1°) to achieve this. Altogether these actions units form the process of eating morsels and over time, the idea to eat dinner is accomplished in physical fact. The hierarchy of sensorimotor intentionality results in the description of the system as built on the primacy of action units (1°) that become organised into 'action chains' (2°) made to accomplish goals distal to the immediate present (3°) in both the time and the affordance space of the present moment. Each primary link in the chain of the project is an action unit with a discrete, prospective property of movement toward its own, local sensorimotor goal with its own, local intention. In kinematic terms, this is skilfully effected in a single phase of acceleration of the effector, the hand in this case, followed by a single phase of deceleration of the effector to the target. Each single action unit lasts typically under one second and only rarely are these single action units longer. Thus, in the case of eating dinner, action units 'i-v' are chained and organised to 'eat morsels' of food that altogether take several seconds. The super-ordinate goal to 'eat dinner' coordinates a series of projects to 'eat morsels', taking many tens of seconds or minutes to complete. This higher-order intention coordinates the series of projects that, in turn, organise their series of action units.

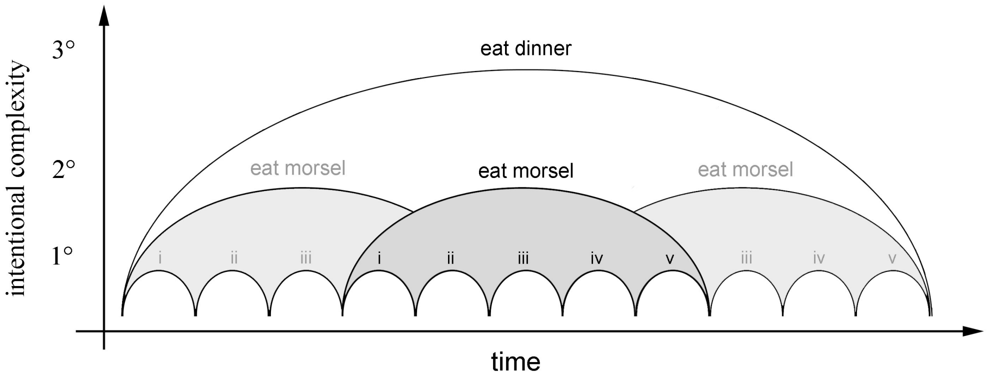

Figure 1. Schematic of the organisation of three levels of complexity of sensorimotor intentionality: (1) a primary sensorimotor intentionality operative in individual action units; (2) a higher-order, secondary sensorimotor intentionality that structures and coordinates the primary ones; and (3) a tertiary intentionality that structures the ones below it. In the example illustrated, the distal tertiary intention to 'eat dinner' is enacted by a sequence of repeated secondary levels of sensorimotor intentionality, each 'eat morsel' itself composed of a sequence of more proximal sensorimotor actions. The primary level is the action units themselves, sequentially ordered here as 'i' to 'v' giving an action chain of (i) moving the arm to the food, (ii) grasping the food, (iii) moving the food to the mouth, (iv) releasing the food into the mouth, and finally, one link to represent (v) mastication and swallowing. The overlapped primary and secondary levels represent simultaneous activity.

Intentionality or goal-directedness pervades the system both bottom up and top down. The individual actions that make up the physical expression of the goal to 'eat dinner' and 'eat morsels' are themselves intentional or directed towards some content in their nature as prospective sensorimotor actions *as well as* by virtue of their being guided by the secondary and tertiary super-ordinates. Thus, the higher-order and more abstract goals guide and organise the lower-order sensorimotor actions into sequences and assemblies that fulfil their purpose. Similarly in the downward direction, the primary sensorimotor actions are themselves composed of a coordinated sequence of neuromotor actions that, organised prospectively, carry out the task of that single action. For example, to move the arm to the food (action 'i', Figure 1) requires (a) lifting the arm vertically, (b) displacing the arm proximo-distally, and (c) lowering the arm to the food. Again, each of these subcomponents of the action unit requires its own organisation of contraction and relaxation of individual muscle fibres that must also be coordinated, and there is argument and some evidence to suggest that even these subcomponents of action units must be prospectively controlled (Lee, 2009), so that altogether there may exist a deep hierarchy of prospective organisation.[8] We have shown prospective organisation of sensorimotor control indicates a primary sensorimotor intentionality in simple, single agent action organisation (primary sensorimotor intentionality) that gives psychomotor units of intention-in-action that, with development, become serially organised into projects to achieve proximal action goals (secondary sensorimotor intentionality), and further developed to achieve compositions of projects that span greater periods of action space-time (tertiary sensorimotor intentionality).

These units appear to be characterised by consistent temporal ranges. Motor control studies of single action unit tasks (pre-reach in early infancy, Carvalho et al., 2007; reach at 9 months, von Hofsten and Ronnqvist, 1993; reach in adulthood, Jeannerod, 1984; hand to mouth travel, Fogassi et al., 2005 & Lee et al., 1999; hand to ball travel, Lee et al., 1983; and hand to target travel, Craig et al., 2005) and proximal projects of serially organised action units (*e.g.* reach-to-grasp-to-eat and reach-to-grasp-to-place, Jeannerod, 1984; Cattaneo *et al.*, 2007) indicate a relatively consistent temporal organisation of these units irrespective of developmental advance or task particulars (Table 1).

It is from this position that we expand our consideration of sensorimotor intentionality as framing and giving structure to cognition.

Table 1. Units of Sensorimotor Intentionality.

Level	Unit Type	Description	Temporal Range
Primary	Action Unit	a single continuous velocity to a goal, for e.g. an arm movement to a body-space or physical object goal.	*ca.* 200-1200ms
Secondary	Proximal Project	Coordination and serial organisation of multiple action units for a proximal goal, for *e.g.* reach-to-grasp or reach-to-grasp-to-eat.	*ca.* 1000-3000 ms
Tertiary	Distal Project	coordination and serial organisation of proximal projects to achieve a higher, abstract, distal goal, for e.g. cooking a dinner.	> 3000 ms

Expanding Knowledge and Structuring Cognition

Distal goals are abstract from the immediate present and their content is not available to the single action units outwith higher-order contexts. They are at least a few seconds away requiring multiple action units to reach and so are distal in terms of action affordances – more immediate, more proximal steps are required to reach them. Though one may be physically close to the object of intention, serially organised sensorimotor steps are required to act in the right way on that object to satisfy the goal, such as in the goal to eat a dinner just described. In more extensive examples of imaginative abstraction, the objects themselves can be totally absent from the immediate perceptual world and therefore the thought for action must rely on memory and prospective knowledge to structure the process of acquiring them. For example, one knows how to walk into one's house, knows the complex arrangements of opening cupboard doors, jars, and other containers, and knows then how to select, combine and cook the foods in them to prepare a dinner. The whole process involves coordination of embedded sensorimotor action units together with all the faculties of human cognition – learning, memory, imagination, *etc.* – giving an abstracted, higher-order sensorimotor organisation. But the intentional nature of these higher order cognitive states are first and foremost structured by bodily knowledge built by past experiences of practical sensorimotor intentionality, and re-enacted through them.

Experimental data show that distal goals shape proximal sensorimotor action (*i.e.*, the 3° and 2° levels shape the 1° level action patterns). For example, when grasping a bottle, the posture of the arm – part of its primary and proximal realization – differs depending on whether the secondary goal is to shelve it or to serve some wine (Jeannerod, 1999). The more distal and abstract the goal becomes, the more sophisticated its level of sensorimotor complexity, and additional supporting systems become necessary for increasing memory, planning, and the self-regulation of arousal, interest, and energy resources over longer periods of time. These are the hallmarks of the so-called 'executive functions'. The development of capacity for action from proximal to more imaginative distal goals is therefore a major step in the evolution of cognitive power (Pezzulo and Castelfranchi, 2009).

With the development of more spatiotemporally distant goals there is the need for coordination of the organism's primary goal states and the means to achieve these by the manipulation of stored information. Our proposal is in line with a growing body of literature that proposes a continuity between the agent's sensorimotor interactions in the immediate present and the development of higher-order cognitive processes, such as memory and representational capacities (*e.g.* Clark, 1997; Haggard et al., 2008; Jeannerod, 1994; Pezzulo, 2011; Pezzulo and Castelfranchi, 2009; Wheeler, 2005). We claim that to offer an adequate account of the representational structure of mental states, one must take into account the continuity of structure in the development of bodily intentionality or goal-directedness, a continuity we have termed here 'sensorimotor intentionality'. Given this continuum, it becomes possible to view the development of higher-order cognition as rooted in primary sensorimotor processes, and conversely cognitive processes in the mature system understood as governed by a primary, pre-reflective bodily intentionality.

An application of the notion of sensorimotor intentionality: Motor control in autism

Our model is in agreement with, and may shed new light on, recent data that identifies dysfunction in the capacity to prospectively control movement to goals in children with autism spectrum disorders (Bogdashina, 2003; Cattaneo et al., 2007; Fabbri-Destro et al., 2009; Nazarali et al., 2009; Rinehart et al., 2006; Rogers and Ozonoff, 2005). This subtle, but significant sensorimotor deficit might underpin the more characteristic symptom of social isolation and emotional distress, and help to explain how certain imitation-based therapies are able to form psychological and emotional connection between individuals where they are otherwise apparently not possible (Escalona et al., 2002; Field et al., 2001; Nadel, 2006; Williams et al., 2004). An early growth error in brainstem systems serving *prospective motor timing* may undermine one's capacity to enact desired sensorimotor intentions, regularly thwarting success, creating distress and isolation, and consequent autistic social and emotional compensation (Trevarthen & Delafield-Butt, 2013b).

If a primary deficit exists in the capacity of ASD individuals to prospectively control movements to goals, so too would a deficit likely exist in their capacity to implicitly understand another's intentions, *i.e.* intentions manifest in movement, when observing the other, and indeed this is what the data suggest (Cattaneo et al., 2007; Fabbri-Destro et al., 2009). Experiments show that children with ASD fail to prospectively 'action chain' when performing a task such as a 'reach to grab' or 'reach to eat'. Where typically developing children adjust their first action unit dependent on the final goal of the project (*c.f.* Jeannerod, 1999), children with ASD do not. The failure to action chain is, in our sensorimotor intentionality parlance, a failure to form secondary sensorimotor intentionalities (2° level in Figure 1), or to communicate continuity between levels.

But this is not the only deficit in prospective control of movement identified in ASD. There is an additional failure in simple, single action unit tasks, such as in the initial reach to the object without any further, secondary goal (Nazarali et al., 2009; Rinehart et al., 2006). The type of disturbance to the action pattern varies depending on the task sub-group examined. For example, in a reach-to-grasp task individuals with ASD grouped by low or average/high intellectual ability (based on full-scale I.Q. scores below and above eighty, respectively) exhibited different movement kinematics to each other, but both groups acted significantly differently to typically developing children (Mari et al., 2003). The differences between ASD groups were thought to reflect different compensatory coping strategies for a primary deficit in what the authors call 'motor planning', in other words, the prospective capacity of perception and action. It is becoming clear that prospective control is affected in ASD and that this is a whole-body problem not restricted to visuo-motor goal-directed actions. Experimental evidence of postural adjustments and muscles tensions during load shifting shows prospective control of whole-body posture and body-space goals are also disrupted, indicating a primary, global deficit in prospectivity (Schmitz et al., 2003).

The continuity we describe for sensorimotor intentionality across levels of action abstraction and 'planning' makes sense of these goal-directed single action and action chain tasks as disruptions in the primary 'action unit' level (1° level in Figure 1) and secondary 'proximal project' level (2° level in Figure 1) of organisation of sensorimotor intentionality. Our model points to a common, underlying concern with basic prospective control and its integrative psychological capacities of intentional action expressed across its levels of organisation. This feasibly includes higher-order abstract goal organisation (3° level and higher in Figure 1) that may be disrupted as part of this continuum.

Our model suggests the neural systems responsible for such a possible primary deficit are likely to be closely related to the midbrain and upper brainstem regions associated with the 'primary control system' (Merker, 2007; Panksepp and Northoff, 2009; Penfield and Jasper, 1954). And there is evidence to support this claim. Magnetic resonance imaging of the brains of autistic children and typically developing controls indicate an early, prenatal developmental concern is a reduction in size of the brainstem and midbrain at birth, a feature over-compensated for with excessive growth postnatally (Hashimoto et al., 1995). Detailed neuroanatomical investigation of brain material from autistic children also indicate limbic midbrain structures and brain stem regions are affected in children with ASD (reviewed in Bauman and Kemper, 2007). Of particular note in these data is a reliable abnormality in the inferior olivary nucleus (Arin et al., 1991; Ritvo et al., 1986; Bailey et al., 1998), a prominent lower brainstem nucleus known to be involved in perceiving and controlling the *timing* of movement (Welsh et al., 1995). Precisely how this region functions is a matter of some debate, but its relevance to ASD symptomology is clearly apparent (Welsh et al., 2005), especially in light of these new data on the deficit of prospectivity in ASD. The biomechanics of movement require a prospective temporal distribution of motor forces for its parsimonious, efficient form of acceleration and deceleration to a goal. In these studies of ASD motor impairment, it is the timing of these forces that appears disrupted, as if they are, at least in part, 'de-coupled' from the goal and lose their primary prospective quality.

The suggestion is that compensatory strategies are employed and evidenced in the disrupted timing of movement. The data on motor impairments in ASD suggest a primary deficit in the capacity to perceive and act prospectively, limiting one's motoric capacity to time control of the actions of the body and their perceptual consequence, but therefore also limiting their intentional, expressive and affective content in timing prospective movement dynamics. The nature of expressive content in movement is one of prospective timing of its dynamics, a feature especially elaborated in the time-based arts of music, drama, and dance (Stern, 2010). The timings of these are necessarily prospective (Lee, 2009; Schögler et al., 2008). If the goal-directedness of the person is part-and-parcel of the sensorimotor system, as our reasoning suggests, then the intentional capacity of the person and his capacity to organise perception and action information will be comparably disrupted. Our proposal establishes that understanding the person's goal-directed engagement with the world cannot be parsed into a purely disembodied 'mental' component, which determines content-directedness of intentional states like beliefs, perceptions, *etc*., and a purely non-intentional 'physical' component which then obeys the commands of the mental. The body, as sensorimotor intentionality, is itself the person's pre-reflective goal-directedness. Disruption in sensorimotor intentionality accordingly results in a disruption in a fundamental pre-reflective mode of meaningful engagement with the world.

An hypothesis of disruption in sensorimotor intentionality in ASD may explain why imitation-based therapies can be effective. Pre-verbal intersubjective connection between partners is made through psycho-motor acts with cross-modal fluency between voice and gesture (Reddy, 2008; Stern, 1971; Stern et al., 1985; Stern, 1985; Trevarthen, 1986; Trevarthen, 1998; Tronick, 2005; Tronick, 1977). Expressive acts such as arm gesturing and vocal utterance, like all voluntary movement, requires prospective control and it is through the form and flow of the movements of the body and voice that intention, affect, and interest is conveyed (Stern, 2010; Trevarthen et al., 2011). They give regular 'narrative' patterns of engagement that generate meaning and value to an interpersonal relation (Bruner, 1990; Frank & Trevarthen, 2012; Gratier and Trevarthen, 2008; Stern, 1985; Trevarthen & Delafield-Butt, 2013a). If the timing and capacity for prospectively controlling intentional movement is disrupted, then so will one's capacity for expression be affected, altering the “vitality dynamics” that express non-verbal feeling and intention in bodily and gestural movement (Stern, 1999; Stern, 2010). Reciprocally, one's partner may then find it difficult or incomprehensible to relate to the feelings and intentions bound up in those movements.

Such a situation was found in a study of monozygotic twins where one twin developed autism and the other developed typically. The rhythms and expressions of the autistic twin in normal, pre-verbal childhood games of teasing and tickling were different than those of the typically developing twin, and the father was unable to reciprocate, creating an exacerbating interpersonal dynamic in everyday games and interactions (Trevarthen and Daniel, 2005). In contrast, the imitation-based therapy, 'intensive interaction', puts importance on the role of creative imitation in therapeutic interactions with individuals with ASD (Caldwell, 2006; Nind, 1999; Zeedyk et al., 2009). Even stereotypies are regarded as affective sensorimotor acts capable of initiating communication. The therapist attends to the movements of the patient, attuning to them with her own body movements to begin to generate an implicit, affective, and inter-subjective psycho-motor connection, thus enabling the patient to see himself reflected the actions of the other.[9] Patient and therapist, like the infant and mother, are said to be affectively 'attuned' to each other through sensorimotor acts.

A motor developmental theory with focus on full therapeutic recovery for individuals with autism spectrum disorder has had some success in treating individuals with ASD using a fixed routine of intense goal-directed motor guidance (Solomon et al., 2012). The approach develops motor skill in reach-to-grasp, reach-to-grasp-to-place, and sorting tasks together with routines that challenge exploration and development of whole-body postural integrations. Therapeutic intervention facilitates development of primary and secondary sensorimotor intentionality through fixed, repeated, and rigorous rehearsal and guidance, features of basic motor skill considered within this theory to be fundamental and necessary for subsequent social, emotional, and cognitive development, proposing a primary deficit and target for therapeutic administration in control of basic intentional actions (Stroh et al., 2008).

Imitation-based therapies tap into a conceptual insight well-documented in the phenomenological philosophy tradition in its treatment of intersubjectivity as an embodied phenomenon. Husserl and Merleau-Ponty extensively investigated the role of the 'lived body' in enabling one's awareness of other minds (Husserl, 1960; Husserl, 1973a; Husserl, 1973b; Husserl, 1973c; Merleau-Ponty, 1945; Merleau-Ponty, 1964). They advanced a phenomenological claim that one experiences one's body in a way one experiences no other thing and one's awareness of being an embodied subject of experience enables one to grasp other minds as similarly embodied. Interpersonal integrations between perceptions of others and proprioceptions of oneself, and intermodal integrations between sensory and motor elements characterising one's lived body, enables understanding the body of others as the locus of a subject's perceptual and proprioceptive experience, and thereby as a sensorimotor system similar to one's own. Merleau-Ponty elaborates on this embodied foundation of intersubjectivity with an example of a fifteen-month-old infant who opens her mouth as he takes one of her fingers between his teeth and gently bites it (Merleau-Ponty 2002, p. 410). Why does the child do so? Merleau-Ponty explains, "'Biting' has immediately, for [her], an intersubjective significance. [She] perceives [her] intentions in [her] body, and my body with [her] own, and thereby my intentions in [her] own body." (Mereleau-Ponty 2002, p. 410). Perceiving the other's intentions in one's own body constitutes an ontogenetically primary form of mindreading, or transference of awareness of one's own sensorimotor system onto the body of the other (Merleau-Ponty 1964, pp. 117-118) in what is now recognised to be mediated, at least in part, by significant overlap in neural function of perceiving, imagining, and acting motor intentions (Gallagher, 2008; Gallese, 2013; Sinigaglia and Rizzolatti, 2011).

Situating the discussion of motor-based therapies on available conceptual frameworks of embodied subjectivity and intersubjectivity not only helps formulate explanatory concepts to account for the success of these therapies but also allows refinement and further improvement of the therapies within new conceptual framework.

Conclusions

In this paper we advanced two conceptual claims, namely, (i) sensorimotor behaviour is governed by a pre-reflective, bodily form of intentionality or goal-directedness which we identify as sensorimotor intentionality and (ii) the intentional structure of mental states, or the feature of mental states to be about something, is traced to the development of prospective motor control from before the second trimester *in utero* onward. Thus, we argue that there exists a continuity of structure of intentionality, as reference to a content or goal-directedness, from its first expression in simple prospective agent action to abstract conceptually-backed adult intentions. The psychological study of the intentional structure of mental states must be grounded in the study of ontogenetically primary bodily action and engagements of the cognitive agent with its environment.

The necessity of prospectivity in motor control and the necessity for mental states to be expressed through motor control implies that this simple structure of anticipation of self-produced consequences of action – whether directed to an external object or simply within the action space of the body, exploring contingencies and changing action affordance – is a primary building block on which mental processes may be built. Thus, the intentional structure of complex mental states is ingrained in and arises from the structure of basic sensorimotor activity.

We propose the following definition of sensorimotor intentionality with reference to its three levels of organisation:

> *Primary Sensorimotor Intentionality.* Self-generated action prospectively organised with anticipation of proprioceptive and/or exteroceptive consequences. Generates sensory contingencies that structure a basic pre-conceptual[11] sensorimotor knowledge of self and environment. It does not require reflexive thought. Expression in limb, head, or trunk typically enacted by single, continuous velocity toward a 'goal' with a stereotyped action pattern lasting under one second.[10] Mediated by spinal cord and brainstem integration. Maintains prospective coherence across the body.
>
> *Secondary Sensorimotor Intentionality.* Includes consequential affordances for future action within a self-generated primary, prospective action. Enables serial organisation of two or more action units altogether prospectively organised to achieve a distal goal. Requires knowledge of the means and effects of individual action units, and their organisation into projects requires basic abstract planning. Example projects include reach-to-grasp or reach-to-grasp-to-place, and locomotion to achieve a particular location. Projects typically last one to several seconds. More extensive sensorimotor knowledge becoming conceptual. Reflexive thought is not necessary. Maintains prospective sensorimotor coordination and integrity across the project.
>
> *Tertiary Sensorimotor Intentionality.* Serial organisation of secondary sensorimotor intentionality projects to achieve conceptually-backed, reflexively-defined goals. Includes knowledge of the consequent affordances

of projects and their ramifications. Enacted through projects of projects that expand over many seconds, minutes, or hours and in adult human life may contain conceptual drivers that organise actions to achieve goals months or years away, for *e.g.* the organisation student behaviour in the present moment ultimately to achieve graduation, or to enable further factors beyond. Over child development goals build in their complexity and imaginative abstraction. Requires cortical function together within brainstem integration. Maintains prospective behavioural coherence.

Thus, we identify the root of intentionality in the invariant prospective motor structure in simple action units and advance a hierarchical model for their serial organisation into projects of action units and projects of projects of action units as the principal framework for development of intentionality from basic to higher levels, affording advancement of prospective reach to include abstract, reflectively conceived conceptual goals that become expressed back through psychophysical immediacy in its basic levels. Higher levels of sensorimotor intentionality develop in concert with maturing capacities of memory and planning, especially in relation to cortical development across a child's life.

We conclude with a reminder that serial organisation of actions into projects and projects of projects enables complex meaning to develop within the individual human organism as it gains mastery of its actions and their consequences. These sensorimotor projects deliver control of the inanimate world of objects, but also begin to afford motor mastery of social engagements with other individuals.

We have highlighted the need for a conceptual framework for understanding some core features of cognition as an achievement of embodied agency. We have identified at least one component of embodiment, namely, an ontogenetically primary and pre-reflective form of bodily intentionality that we term 'primary sensorimotor intentionality', which plays a crucial role in structuring the development of mental states and their content-directedness. Future research within this framework requires examining further the neurological basis of simple prospective motor control and the development of primary sensorimotor intentionality into higher levels. The relationship between consciousness, affects, and sensorimotor intentionality will also take additional scholarship to elucidate further, but promises to be especially fruitful multidisciplinary work given the growing contemporary strain of phenomenology defining the experiential structures in a situated, embodied experiencer (Gallagher, 2008; Gallagher, 2012; Zahavi, 2005; Zahavi, 2006) advancing adjacent to improving understanding of the neurobiology of primary conscious agency (Vandekerckhove and Panksepp, 2011; Merker, 2007; Solms and Panksepp, 2012; Vandekerckhove and Panksepp, 2009; Panksepp and Northoff, 2009). Moreover, our model is aligned to the three levels of emotional-affective processing proposed by Panksepp (2011), and their neurobiological substrates are in approximate agreement. The role of contribution of evaluations of self-in-relation made with affective appraisal and enacted through sensorimotor intention promises especially important understanding of value-laden affective sensorimotor consciousness and decision making, and its development in childhood.

We expect these interdisciplinary routes will yield useful insight into psychological disorders, such as the autism spectrum disorders we have commented on here, giving both clinical and research psychologists improved understanding of the motivational, affective, and intentional components of action.

Thus, we give a developmental and unified mind-body account of a quintessential feature of the embodied human mind – its intentionality or ‘aboutness’. This “something as object” essential for mental experience is inherent in the structure of sensorimotor activity from its beginning, and grows with increasing precision and prospective capacity as one develops in childhood, and life.

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Footnotes

[1] Metaphysical enquiry of the objects of mental states questions whether they are real existing objects in the physical world or whether they enjoy a special status beyond the subjective-objective world divide. This is the subject of long-standing philosophical debate. In this paper we focus on the object-directed nature of mental states and not on philosophical debates about the metaphysical status of mental state objects.

[2] Our exploration of cognition as embodied action focuses on both psychological and neurocognitive mechanisms of agent-environment interaction. Thus, we do not subscribe to any proposal that may overlook the role and importance of neural mechanisms in enabling an embodied agent's meaningful interactions with the environment. Our approach is akin to Hurley's proposal of the "shared circuits model" (Hurley, 2008) whereby a satisfactory understanding of neurocognitive mechanisms must take the embodiment and situatedness of the cognizer non-trivially. Hurley writes and we concur, "At the subpersonal level of description, information is processed and the cycling of causes and effects knits actively embodied nervous systems into environments they interact with." (Hurley, 2008, p. p. 3).

[3] Brentano is referring to mental objects and not necessarily to physical objects in the environment. Like the mental experiences of physical objects, mental objects are configurations, or images of appraisals and sensations. The tight relationship between knowledge of physical objects and their mental object correlates is an epistemological point Piaget (1954) reasoned is rooted in sensorimotor experience.

[4] Tau theory is a mathematicopsychophysical perceptuomotor control theory first developed at Gibson's laboratory at Cornell and subsequently generalised (Lee, 1976; reviewed in Lee, 2009). It is recognises three basic principles of animal movement: (i) all purposive movement entails *prospectively controlling* the closure of action-gaps, *e.g.* a distance gap when reaching or an angle gap when steering; (ii) the sole informational variable required for controlling gaps is the *relative rate of change of the gap*, *i.e.* the time derivative of the gap size divided by the size, which can be directly sensed and controlled; and (iii) coordinated movement is achieved by keeping the relative rates of change of gaps in constant ratio. Tau information is simple information that eliminates the need for complex sets of sensorimotor calculations, giving a parsimonious, amodal informational form for a wide variety of sensorimotor goal-acquisitions (Lee, 2009; Delafield-Butt *et al.*, 2012). Thus, employment of tau information in sensorimotor control necessarily indicates prospectivity.

[5] "The self-repeating or 'circular' reaction… is seen to be fundamental and to remain the same, as far as structure is concerned, for all motor activity whatever: the only difference between higher and lower function being, that in the higher, certain accumulated adaptations have in time so come to overlie the original reaction, that the conscious state which accompanies it seems to differ per se from the crude imitative consciousness in which it had its beginning." (Baldwin, 1895, p. 23).

[6] Our proposal thus accommodates the various levels of content in goal states targeted by actions while challenging the assumption that the only form of intentionality is an 'internalistic' one which gives commands to a mechanical body that executes the commands for attaining various goals. No matter whether the action is 'for its own sake' or the action is 'a means to another end' our claim is bodily action involves a form of bodily intentionality. Moreover, the notion of sensorimotor intentionality remains equally

important even when considering actions that are 'means to another end' (for example, conceptually formed goal states) to dispel of the notion of the acting body as non-intentional and mechanistic (see also Searle, 1983). We thank an anonymous reviewer for helping clarify the point.

[7] For a detailed discussion of the Cartesian roots of mechanistic explanations of bodily behaviour see Wright and Bechtel (2007), who point out, "The idea that natural phenomena – including physiological processes – are the activities of mechanisms was already a radical departure from the traditions based on Aristotelian science, which endorsed teleological explanation. Yet Descartes made a further, controversial move in developing his mechanical philosophy. He maintained that *all* behaviour exhibited by animals was generated mechanically and so did not require positing purposes or goals… Moreover, Descartes did not see any reason to distinguish human and non-human animals in this respect; any human behaviour that was comparable to that of non-human animals was likewise the product of mechanisms operative in the physical body." (p. 33-34)

[8] The psychobiological roots of sensorimotor intentionality are ultimately a matter both of metaphysics and future work, and beyond the scope of this paper. Here, we maintain its existence in an agentive capacity dependent on integrative *neural* activity with associated sensory and motor systems, and their necessary prospective nature. The boundary between an agentive sensorimotor intentionality and the prospectivity within other so-called 'automatic' processes is an interesting one. For example, Pacherie (unpublished manuscript) notes that even actions as simple and seemingly automatic as eye saccades appear to be controlled by sets of predictive mechanisms that allow for an internal simulation of eye movements in the absence of overt saccades (Berthoz, 1996), suggesting lower level prospective capacities in what are commonly assumed to be non-intentional, fast, and automatic neural subsystems. Indeed, Lee (2009) provides cursory evidence to show tau prospective control in the eye saccade itself. These data suggest a non-conceptual intentionality may extend deeper into simple neuromuscular circuits, and others argue intentionality in its widest sense is a property of living systems generally. For *e.g.*, Fitch (2008) argues for a 'nano-intentionality' present in the actions of individual cells, Thompson (2007) advances argument for purposiveness in basic non-neural biological systems, and new evidence indicates τ information may be employed in systems as simple as single-celled protozoans (Delafield-Butt et al., 2012; Delafield-Butt and Schögler, 2007). More work is needed to examine the nature of such low-level prospectivity and its relation to development of human agency; it is on the basis of these 'automatic' systems that human experience and life are sustained.

[9] This brings to mind Winnicott's (1971, p. 112) famous perspective that what the infant sees in the expressions of the mother is oneself reflected back, through her expressions of affective appraisal, *e.g.* the mother perceives the infant and expresses back her feelings of appreciation and love. The quality and dynamic of this reflection, then, determines a quality of one's social development. The acts of engagement provide important contingent responses that, if disrupted or thwarted by stress or disease on one side, can lead to distress and pathology on the other (Murray et al., 1996; Tronick et al., 1978).

[10] A test of whether or not a particular action is guided by a sensorimotor intentional is offered by General Tau Theory. Those actions prospectively guided with anticipation of their end-state can be measured and tested against the theory. Those that are successfully

prospectively guided will fit the theoretical prediction, whereas those that are not will not. For example, Craig et al. (2000) found that prematurely born babies with neurological complication could not prospectively regulate their intraoral pressure using tau information when sucking for feeding, whereas those with no complication could. This raises the important concern that neurological disruption in basic prospective sensorimotor processes is also a disruption to capacity of primary sensorimotor intentionality, which can lead to downstream psychological consequences (Trevarthen & Delafield-Butt, 2013b).

[11] This can also be considered ‘proto-conceptual’, since prospectivity requires an anticipatory *knowledge* of future eventualities that will be created by the action, however simple this might be.