Vygotsky, Luria, and the Social Brain

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> "In order to explain the highly complex forms of human consciousness one must go beyond the human organism. One must seek the origins of conscious activity and 'categorical' behavior not in the recesses of the human brain or in the depths of the spirit, but in the external conditions of life. Above all, this means that one must seek these origins in the external processes of social life, in the social and historical forms of human existence." (Luria, 1981, p. 25)

The question of how children acquire the capacity to regulate their own cognition and behavior has given rise to an impressive body of recent research. As the contributions to this volume show, researchers in the fields of developmental psychology, developmental cognitive neuroscience, cognitive psychology, and cognitive neuropsychology have contributed in various ways to our understanding of executive functioning (EF), defined as the ability to control, inhibit, and monitor one's own physical and mental activity (Russell, 1996). EF has been suggested to be important for meeting a variety of challenges encountered by children in their cognitive (Carlson, Mandell, & Williams, 2004) and social (Blair, 2002; Shoda, Mischel, & Peake, 1990) lives, while EF deficits have been implicated in developmental disorders such as ADHD (Barkley, 1997) and autism spectrum disorders (Happé, Booth, Charlton, & Hughes, 2006; Hill, 2004; Pennington & Ozonoff, 1996). A tendency to regard EF as a unitary construct, stemming partly from evidence for EF deficits following lesions to the prefrontal cortex (Baddeley, 1986; Luria, 1966/1980; Shallice, 1988), has yielded in recent years to a view of EF as consisting of a group of independent subprocesses specialised for functions such as planning

(Shallice & Burgess, 1991) and task co-ordination (e.g., Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986; Miyake et al., 2000).

For the most part these findings have been interpreted within a view of EF which sees it as being driven by the maturation of the prefrontal cortex in the first five or so years of life (e.g., Luria, 1973). Among the evidence cited in support of this view are findings that lesions to the prefrontal cortex are behaviorally silent in young children (Eslinger, Biddle, & Grattan, 1997; Golden, 1981; although see Zelazo & Müller, 2002, for a review of contrasting views). Although the idea that EF is localized exclusively in the frontal lobes has been questioned in recent years (Zelazo & Müller, 2002), the assumption that children's executive capacities are developmentally regulated by cortical maturation remains deep-rooted (Diamond, 2002; Diamond, Prevor, Callender, & Druin, 1997; Welsh, Pennington, Ozonoff, Rouse, & McCabe, 1990). The value of seeking neurological specificity in tracing the rich array of functions that contribute to EF is demonstrated in the recent separation of 'hot' from 'cool' EF, each associated with particular patterns of localization in the brain (Zelazo & Müller, 2002).

This view of EF development as being driven by cortical maturation is most commonly associated with the Soviet neuropsychologist, A. R. Luria (e.g., 1966/1980; 1973). Luria's status as a founding father of modern neuropsychology (Mecacci, 2005) has occasionally served to obscure the breadth of his thinking about causality in human development. In particular, researchers in the field of EF have sometimes neglected Luria's importance as a proponent of a sociocultural approach to development, within which the causes behind EF development are sought as much outside as within the brain. In this chapter, I propose that close attention to Luria's background in the historical-cultural approach, which was emerging in Soviet

psychology at the time of his entry into the field (Luria, 1979), can be of value in our attempts to disentangle the developmental interrelations among social interaction, social understanding, and EF. In the first section, I briefly review evidence for the developmental linkage between EF and social understanding. In the second section, I examine the potential value of a Vygotskian interfunctional approach to explaining these developmental relations. In the final section, I consider these relations in light of Luria's co-constructivist approach to neurodevelopment which allowed for bidirectional causal influences between biology and social environment.

Executive functioning and social understanding

Among Luria's many accomplishments as a psychologist and neurologist was his recognition of the importance of a class of psychological functions involved in planning, monitoring, and inhibiting thought and action. Luria's functional analysis involved individuating these capacities according to what they accomplish in terms of cognitive and behavioral outcomes, rather than treating them as explanatory constructs in their own right (Müller, Jacques, Brocki, & Zelazo, in press). In turn, this functional approach allowed Luria to frame hypotheses about EF development independently of considerations about their neurological underpinning. The subtlety of Luria's thinking about neurological functions, particularly his emphasis on the necessity of examining the functioning of cognitive subsystems in the context of the roles they play in larger functional systems, has often been obscured by the 'modularizing' tendencies that characterize much contemporary work in this area (Zelazo, Carter, Reznick, & Frye, 1997).

Indeed, Luria explicitly rejected the idea that a psychological function can be equated with "a direct property of a particular, highly specialized group of cells of an organ" (Luria,

1966/1980, p. 21). To the extent that a function can be localized in the brain at all, it is as "a network of complex dynamic structures or combination centers, consisting of mosaics of distant points of the nervous system, united in a common task" (ibid.). Luria attributed the inspiration for his anti-modular view of the localization of functions to Vygotsky's (e.g., 1934/1965) views on the need to reconsider existing principles of brain localization in doing justice to the complexity of functional systems (Luria, 1965)[1]. Arguing that any specific higher cognitive function "is a product of an integral activity of a very differentiated, hierarchically constructed complex of separate zones… of the brain" (Vygotsky, 1934/1965, p. 383), Vygotsky set out three main tenets underlying the functional systems approach: the assumption of dynamic and developing interfunctional relations, the assumption of the hierarchical organization of mental functions such that complex functional systems are built up through the integration of more primitive functions, and the assumption that psychological activity is rendered meaningful by its reflection of external reality. For present purposes, three key implications of this approach can be identified: (1) the need for new principles for localization of psychological functions in the brain which take account of how elementary functions are combined into dynamic, integrated functional systems; (2) the need for a new attitude to the significance of damage to different cortical areas at different points in development; and (3) the need for an interfunctional[2]

[1] It is important to emphasize that 'localization', in the sense employed by Vygotsky (1934/1965), does not entail modularization. Vygotsky was concerned to trace the complex distribution of psychological functions within the brain, and warned explicitly against the assumption that functions could be traced to unitary anatomical loci.

[2] Central to Vygotsky's enterprise was the acknowledgement of the importance of "interfunctional relationships" (1934/1987, pp. 43-44), by which he meant the changing developmental relations between cognitive functions such as thinking and language. The significance of psychological interfunctionality for EF and SU development is considered further in the next section.

approach to higher mental functions such as EF. These implications of the functional systems approach for our understanding of EF and other cognitive processes are considered further in the second and third sections of this chapter.

Contemporary accounts of EF development have paid only scant attention to Luria's construal of EF as a functional system depending on the interaction of hierarchically-organized subsystems whose neurological foci may be spread out across the brain (Luria, 1966/1980). As Zelazo et al. (1997) note, appealing to "narrowly localized, modular mechanisms" (p. 219) has the effect of shifting the burden of explanation from the broader context of an organism's behavior to unobservable mechanisms. Those working within the cognitivist tradition, however, have frequently approached EF in terms of a unitary capacity. One influential group of theories has conceived of EF development as being driven by children's growing capacities to inhibit inappropriate behavior (e.g., Carlson & Moses, 2001). A second group of theories has proposed that working memory changes play a primary causal role in determining how well children are able to use multiple sources of information in planning and monitoring action (e.g., Case, 1995). A third group of accounts, often referred to as complexity accounts (e.g., Zelazo, Müller, Frye, & Marcovitch, 2003), has attributed EF development to children's increasing mastery of hierarchical rule structures, possibly articulated in inner speech. In contrast to competing inhibition and memory accounts, Zelazo and colleagues' view of EF as a functional system involving the integration of language with other cognitive functions is distinctive among cognitivist accounts in its adherence to Luria's functional systems approach to EF.

A thorough evaluation of the relative merits of these different cognitivist approaches is beyond the scope of this chapter. For present purposes, it is sufficient to note two main areas of

challenge for such accounts of EF development: the problem of explaining the control of behavior in terms of processes arising from within the organism, and the related challenge of situating EF development within a social and cultural context.

The first of these challenges relates to the venerable problem of how to account for volitional behavior in terms of chains of mechanistic psychological processes. Accounting for a voluntary act in terms of the causal power of a mental event *C* raises a problem of recursion, whereby one is bound to propose a further mental event *C′* to explain what caused the causal event *C*, and so on (Akins & Dennett, 1986). Without such a mechanistic explanation, one is left with the unsatisfactory alternatives of dualism and reductive behaviorism (Luria, 1981, Ch. 6) or, in Vygotsky's words, "waver[ing] between the poles of extreme materialism and extreme spiritualism" (Vygotsky, 1960). The same point is made in a slightly different way by Zelazo and Müller (2002), who note that the tendency to hypostasize neurological foci or 'centers' to explain a psychological function involves attributing homuncular abilities which fail to provide adequate explanations of complex psychological phenomena such as conscious volition.

The second challenge facing cognitivist accounts of EF is the related one of explaining how the emerging executive functions might be shaped by the social context within which they are developing. Vygotsky's proposed solution to the "historical crisis" in psychology (Vygotsky, 1997), or the problem of providing non-reductivist scientific explanations which go beyond the mere description of complex psychological phenomena, was to seek the origins of such behavior in realms beyond the biological organism. Specifically, Vygotsky's interfunctional approach (see Note 2) allowed him to show how social and cultural factors may become organizing forces in behavior. In contrast, cognitivist accounts typically view EF development as potentially

impacting upon social behavior, but not being developmentally shaped by them. The value of an interfunctional approach in this respect is considered further in the second section of this chapter.

The challenges of providing non-reductive mechanistic explanations that do justice to the social context of ontogenesis have recently been brought into focus in the case of another important aspect of cognitive development in the preschool years. Those capacities brought together under the umbrella terms *theory of mind* and *social understanding* (SU; Carpendale & Lewis, 2004) have so far proved resistant to narrowly modular accounts of their development, while also proving highly sensitive to individual differences in social experience. These parallels between the cases of EF and SU have constituted one reason for the growth of interest in the developmental relations between these two important areas of development. A further reason has been the difficulty in establishing the direction of causation in any relation of influence. Among the important questions that have been considered here are: (1) whether a certain level of SU is a prerequisite for establishing the self-control of behavior (e.g., Perner, 1998); (2) whether a certain level of EF is necessary for making judgements about the mental states of others (e.g., Russell, 1996); and (3) whether individual differences in EF can continue to shape children's social interactions once EF has developed (Hughes, 1998).

A thorough overview of the empirical evidence for the relation between EF and SU is beyond the scope of this chapter. Attempts to account for these relations have typically focused on the issue of the direction of causation, specifically whether SU is dependent on EF or vice versa (see Perner, Lang, & Kloo, 2002, for an evaluation of these two main alternatives; see also Kloo et al., this volume). My assumption in what follows is that our understanding of the EF–SU relation will be enhanced by a direction of attention away from issues of causal direction towards

a focus on the benefits of an interfunctional approach to both of these general classes of psychological process. At the same time, it is acknowledged that the specifics of the developmental relation between these two areas of cognition are far from established, and that future research will continue to elucidate the complex ways in which particular executive abilities relate to the various capacities brought under the umbrella of SU.

An obvious alternative to a simple unidirectional causal model in explaining the relation between two variables is to postulate a third factor which determines change in both primary variables. In the section that follows, I will suggest that a relevant third factor in this case may be children's linguistically mediated social experience. The proposed reconceptualization of the EF–SU relation will, however, go beyond a simple third-factor model, and will instead involve taking an interfunctional approach to both EF and SU development, where each capacity is seen as being built from a partly overlapping set of subsystems. In so doing, I shall advocate a view of both capacities as being constituted of functional systems developmentally structured by social experience.

Interfunctional approaches to EF and SU

The benefits of taking a functional systems approach to the EF–SU relation are apparent on a close examination of Vygotsky's and Luria's ideas about psychological functions and their neuroanatomical localization. Luria (1966/1980) defined one useful sense of the term psychological function as "an organism's complex adaptive activity, directed toward the performance of some physiological or psychological task" (p. 22). Luria went on to argue that this sense of a psychological function is best understood as a functional system comprising "a

complex dynamic ‘constellation’ of connections, situated at different levels of the nervous system, that, in the performance of the adaptive task, may be changed with the task itself remaining unchanged” (ibid.). This systemic view of the cooperation of highly differentiated, interchangeable constituent components allows for change in the profile of the subsystems employed in achieving a fixed task from one occasion to another. For example, the same gross motor action can be performed using different combinations of components of the musculature. Functional systems can thus be characterized as “complex in composition, plastic in the variability of their elements, and possessing the property of dynamic autoregulation” (Luria, 1966/1980, p. 23).

As befitted his interest in neurology, Luria’s primary focus in adopting a functional systems approach was to explore its implications for the localization (see Note 1) of psychological functions within the human nervous system. Although the issue of localization was one that also exercised Vygotsky (e.g., 1934/1965), his primary interest as a developmental psychologist was in determining how different psychological functions with, crucially, different trajectories of development come to interact in the formation of functional systems. For this reason, my focus in this section is on the implications of Vygotsky’s ideas about interfunctionality (see Note 2) for our understanding of the EF–SU relation, with the issue of localization returned to in the final part of this chapter.

One assumption that needs to be clearly articulated here is that the capacities involved in EF and SU are examples of *higher mental functions* (Vygotsky, 1930–1935/1978). In Vygotsky’s theory, the higher mental functions are accessible to consciousness, under voluntary control, and mediated by cultural artifacts such as signs. They are thereby distinguished from the *elementary*

mental functions, which are unconscious, involuntary, and unmediated. The two classes of psychological function develop along two distinct lines of development, the cultural and the biological respectively. In contrast to the elementary mental functions, which are biologically specified, entirely driven by environmental stimulation, and represent a natural endowment shared with some non-human animals, the higher mental functions have their origin in social interactions.

Viewing EF and SU as examples of higher mental functions (Fernyhough, 1996; 2008) entails several important implications for understanding the ontogenetic relations between these two variables. Firstly, it means that a functional systems approach to these variables is particularly appropriate, with the implication that a satisfactory account of how they interrelate developmentally will require attention to the components that interact in forming a functional system. Indeed, the existence of "plastic, changeable interfunctional relations" (Vygotsky, 1934/1965, p. 382) was a central assumption of Vygotsky's systemic approach. Elsewhere, Vygotsky (1934/1987, Ch. 1) argued that the failure to adopt an interfunctional approach when studying complex psychological phenomena was as misguided as would be the attempt to understand chemical compounds in terms of the properties of their constituent elements.

A second important implication is that EF and SU should be considered as higher mental functions whose origins lie in social activity. As noted above, Vygotsky's proposed solution to the perceived crisis in psychology lay in the search for causal influences on thought and behavior in the world beyond the biological individual, particularly in the social world. An interfunctional approach to EF and SU thus avoids the problem typical of cognitivist accounts of seeking the ultimate causes of behavior within the individual.

A third implication is that, as functional systems, EF and SU will be underpinned by shifting agglomerations of interchangeable cognitive elements, the relations among which will have different significances depending on the point in development at which they are observed. In Luria's (1966/1980) words, "at successive stages of their development the structure of the higher mental functions does not remain constant but [those functions] perform the same task by means of different, regularly interchanging systems of connections" (p. 34). A corollary of this is that the significance of damage to functional systems through brain injury will depend on the stage of development at which the damage occurs (Vygotsky, 1934/1965).

Further implications of the functional systems approach for cortical development are considered in the final section. In the remainder of this section, I consider how the interfunctional approach can be applied specifically to the cases of EF and SU, and what benefits result from this alternative to typical cognitivist interpretations of these phenomena.

An interfunctional approach to EF development

Adherents to the sociocultural approach have typically framed the problem of EF ontogenesis in terms of children's developing self-regulation of thought and behavior. Vygotsky (e.g., 1934/1987) argued that self-regulation reaches a major milestone when biologically specified forms of thinking are reformulated by the internalization of semiotically mediated activities (primarily linguistic activities) that are initially distributed or shared between individuals. Specifically, children gain enhanced control over their own behavior when words which were previously used to regulate the behavior of others, or which others have used to regulate the child's behavior, become employed in regulating the behavior of the self. In terms of the

Vygotskian–Lurian approach described above, mediated EF forms a functional system in which prelinguistic capacities for monitoring, planning, and inhibition of behavior begin to relate interfunctionally with the language capacity.

In Vygotsky's view, the revolution that follows from children's beginning use of semiotic systems in mediating their cognition represents the intertwining of pre-intellectual and pre-linguistic strands of cognition, or the fusing of the natural and cultural lines of development (Vygotsky, 1930–1935/1978). The development of self-regulation thus involves "the creation or use of artificial stimuli which become the immediate causes of behavior" (ibid., p. 39), which occurs through the progressive internalization of verbal interactions with others. One important implication of this view is that the causes of behavior should be sought in processes that occur outside the limits of the individual organism. Additionally, the capacities brought under the umbrella of EF will be mediated by signs, primarily words and utterances in natural language (Luria, 1932).

Empirical studies have generally supported Vygotsky's claims about the development of verbal self-regulation through social interaction (see e.g., Winsler, Fernyhough, & Montero, forthcoming). Although Vygotsky did not specify in detail what forms of monitoring, planning and inhibition precede the self-regulatory use of language, it is clear that prelinguistic infants have some rudimentary abilities in this respect. For example, success on the A-not-B object search task requires some level of inhibition of a previously successful action (Diamond, 1991). In Vygotsky's view, the advent of verbal self-regulation transforms these elementary executive capacities through their incorporation into new functional systems. For example, researchers such as Wertsch and colleagues (Wertsch & Stone, 1985) have presented evidence for the

progressive transfer of strategic responsibility from adult to child in dyadic problem-solving contexts, such that children become able to regulate their own problem-solving activity using the internalized dialogue previously shared with more expert collaborators. Empirical research on the social origins of self-regulation thus answers Vygotsky's call for the search for the origins of volitional behavior to be made outside the realm of the individual. In Luria's (1981) words, "we must go beyond the limits of the individual organism and examine how volitional processes are formed for the child in his/her concrete contacts with adults… [T]he source of the volitional act is the child's communication with adults." (p. 89).

The strongest support for Vygotsky's ideas about verbal self-regulation has emerged from research into children's self-directed speech. In his early observations of children's language, Piaget (1923/1959) described a type of speech which appeared to have no communicative function and which he took to reflect the young child's egocentrism. Vygotsky (1934/1987) took issue with this interpretation, claiming that such non-communicative speech (now commonly known as private speech) in fact played an important role in the development of self-regulation. Private speech was seen to constitute a distinctive stage in the process whereby mediated interpersonal activity is internalized to form inner speech or verbal thought.

The empirical predictions which follow from this view of children's non-communicative speech have received support from a number of empirical studies (see Berk, 1992, and Winsler, 2004, for reviews). Consistent with Vygotsky's (1934/1987) claims about the progressive internalization of this form of language activity, private speech has been shown to follow an inverted U-shaped developmental trajectory, emerging in the early preschool years and subsequently dropping away in later childhood (Kohlberg, Yaeger, & Hjertholm, 1968; Winsler

& Naglieri, 2003). In addition, support has been found for Vygotskian predictions about the relation between private speech and task difficulty, particularly the suggestion that private speech levels will peak when the task is pitched at a level appropriate to the child's current level of competence (Frauenglass & Diaz, 1985).

Vygotsky's claims about the importance of verbal self-regulation for EF development entail that children's use of such speech should relate to their performance on those cognitive tasks in which verbal self-regulation is used. In support of this prediction, private speech researchers have documented positive relations between this form of speech and both concurrent (Winsler, Diaz, McCarthy, Atencio, & Adams Chabay, 1999) and future (Behrend, Rosengren, & Perlmutter, 1992; Bivens and Berk, 1990) task performance. Two recent studies have focused particularly on children's verbal self-regulation while solving puzzles of a classic EF task, the Tower of London (Shallice, 1982). Fernyhough and Fradley (2005) made videotape recordings of 46 children aged 5 and 6 as they attempted progressively more difficult Tower of London puzzles. Children's speech was subsequently coded for the use of non-communicative utterances with an apparently self-regulatory function. Children's rate of production of such utterances was positively related to their concurrent performance on the EF task. Similar findings were reported by Al-Namlah, Fernyhough, and Meins (2006), who observed Tower of London puzzle-solving in a sample of 121 children aged four to eight from samples recruited in the UK and Saudi Arabia. Support for Vygotsky's views on the developmental significance of private speech is thus provided by data from classic EF tasks as well as the non-executive tasks typically used in private speech research (such as the semantic task used by Frauenglass and Diaz, 1985).

The functional systems approach thus provides a framework for making sense of emerging evidence for social influences on EF development. If mediated EF is derived from social interaction, as Vygotsky's theory holds, then it should be possible to observe influences of social interactional experience on private speech and EF development. With regard to social influences on private speech development, Al-Namlah et al. (2006) found some limited support for predictions that children's private speech would relate to their culturally specific experience of reciprocal social interaction with adults. In an earlier study, Berk and Garvin (1984) investigated private speech use in a rural Appalachian culture previously characterized as involving low levels of reciprocal adult–child interaction. As predicted, the development of private speech in this sample appeared delayed relative to what would be predicted in a typical American sample. Furthermore, these documented social influences on private speech development have been observed to relate to the cognitive facilitatory effects of this form of speech. In their study of 40 preschoolers engaged in a selective attention task, Winsler, Diaz, and Montero (1997) found that children's production of private speech related to their previous experience of tutoring interactions in which an experimenter scaffolded the child's task performance. Following scaffolding, children who used private speech were more successful on the task than those who did not.

Turning to EF as typically operationalized within the cognitivist tradition, social influences on EF have not to date been the focus of concerted research attention. One exception is a longitudinal study by Landry, Miller-Loncar, Smith, and Swank (2002; see also Landry & Smith, this volume) which showed an association between parental scaffolding of children's task performance at age 3 and EF measures obtained at age 6, a relation that was mediated by

children's language scores at age 4. Landry et al.'s careful longitudinal analysis did not, however, include measures of verbal self-regulation, meaning that it is impossible to establish from their findings whether the benefit in EF performance associated with scaffolding was mediated by private speech (Müller et al., in press).

A functional systems approach to EF, according to which progress from elementary to more advanced forms of EF is determined by developing interfunctional relations between rudimentary executive capacities and language, is further supported by findings of strong relations between children's verbal ability and EF performance (Carlson et al., 2004; Hughes & Ensor, 2005; Perner et al., 2002; although see Müller et al., in press, for discussion of conflicting findings). Further evidence for the value of the approach comes from findings of a facilitatory effect of overt labelling of stimuli in EF tasks (see Müller et al., in press, for a review). For example, young preschoolers who spontaneously used labelling in an attentional control task (requiring the selection of a colored card to receive a differently-colored candy) showed enhanced performance compared to their non-labelling peers (Müller, Zelazo, Hood, Leone, & Rohrer, 2004, Experiment 1). A subsequent experiment in which children in one condition were explicitly instructed to label the stimuli also showed a facilitatory effect of labelling (ibid., Experiment 2).

In evaluating the significance of these findings, it is worth noting that the Lurian tradition of research into verbal self-regulation, within which these labelling studies have been conducted, differs in important ways from the empirical approach adopted by Vygotsky. Luria's empirical approach (e.g., 1981, Chapter 6) relied on observations of children's responses to explicit invitations by an adult experimenter to use labelling and other verbal regulatory stimuli in

performing EF tasks. In contrast, researchers within the Vygotskian empirical tradition have been primarily concerned with children's spontaneous self-directed speech, as generated in a broader range of cognitive contexts than EF tasks. As Berk (1992) has observed, this difference in emphasis means that caution should be exercised in integrating data derived from the two research programs, as the two kinds of speech may not have the same functional or developmental significance. Despite these differences in empirical and methodological approaches, both theorists were in agreement that language performs an important function in EF. In Luria's (1981) words, "[i]t is because of language that humans can delve into the essence of things, transcend the limits of direct impression, organize their purposeful behavior, unravel complex connections and relationships which are not accessible to direct perception, and transmit information accumulated over generations to other persons" (p. 199).

In summary, a Vygotskian–Lurian functional systems approach to EF development makes the following important claims. First, the forms of EF which appear in the preschool period are examples of the semiotically mediated higher mental functions. In contrast, forms of EF which appear in infancy are shared with some non-human animals and form part of the natural, rather than the cultural, line of development. These more primitive forms of EF are not semiotically mediated and do not derive from social interaction, but form the basis for the development of mediated EF when they begin to be incorporated into new functional systems through internalization and the emergence of semiotic mediation. Secondly, EF develops in the context of interpersonal exchanges where more expert partners allow children to participate in activities which they will only later master for themselves (Wertsch, 1985). Thirdly, the Vygotskian–Lurian approach implies that EF will preserve certain characteristics of the social

interaction from which it derives, particularly its dialogic nature (Fernyhough, 1996; 2007; Wertsch, 1980).

An interfunctional approach to SU development

An interfunctional approach to EF can thus provide a powerful framework for making sense of how language can transform existing, biologically specified EF capacities in the creation of new functional systems. As noted above, another important cognitive capacity which may benefit from an interfunctional approach is children's understanding of other people as mental agents. Researchers in this field have faced a challenge in recent years in accounting for the very strong evidence for an involvement of language in children's developing theory of mind or SU[3] (see e.g., Astington & Baird, 2005). For example, several studies have shown SU task performance to be strongly correlated with language ability (Cutting & Dunn, 1999; de Villiers, 2000; Jenkins & Astington, 1996). Among the properties of linguistic discourse that have been proposed to facilitate SU development are conversational pragmatics (e.g., Harris, 1999), lexical semantics (e.g., Peterson & Siegal, 2000), and complementation syntax (e.g., de Villiers & de Villiers, 2000). SU development therefore appears to bear some similarity to EF development in its sensitivity to social experience and environmental, specifically linguistic, input.

This apparent commonality between EF and SU suggests that it may be possible to account for these findings in terms of language interacting interfunctionally with more rudimentary abilities in transforming elementary forms of SU (such as intentional-agent

[3] Given the theory-laden nature of the term 'theory of mind', I prefer the term social understanding (SU; Carpendale & Lewis, 2004). Although the use of both umbrella terms might be thought to obscure important theoretical, empirical, and methodological subtleties, I shall treat them as interchangeable.

understanding) into higher, characteristically human forms. Elsewhere (Fernyhough, 2008) I have proposed that progress in SU development depends on the development of such interfunctional relations between rudimentary forms of social cognition and pre-existing and parallel-developing cognitive abilities, specifically language (or other semiotic mediational systems). Drawing on the Dialogic Thinking (DT) model of cognitive development (Fernyhough, 1996; 2004a; 2004b; 2005; 2006; 2008; in press), I have proposed that the internalization of mediated interpersonal activity described by Vygotsky founds children's capacity to operate with the internalized, semiotically mediated perspectives of others. This claim is in turn based on the assumption that the mediated higher mental functions retain the dialogic character of the social activity from which they are derived (Fernyhough, 1996).

Several testable predictions follow from this view of SU development. One is that SU development should be sensitive to experience of mediated social exchanges in which alternative perspectives on reality are presented (Fernyhough, 2008). The Vygotskian approach to SU development thus provides a useful framework for interpreting data relating individual differences in SU development to social-environmental variables such as mental-state causal talk (Dunn, Brown, Slomkowski, Tesla, & Youngblade, 1991), family size (Lewis, Freeman, Kyriakidou, Maridaki-Kassotaki, & Berridge, 1996), attachment security (Meins, Fernyhough, Russell, & Clark-Carter, 1998), and mind-mindedness (Meins, Fernyhough, Wainwright, das Gupta, Fradley, & Tuckey, 2002; Meins et al., 2003). A second prediction is that progress in SU development should go hand-in-hand with a shift to semiotic mediation in other cognitive domains. Some preliminary data in support of this prediction are reported by Fernyhough and Meins (in press), who obtained measures of self-regulatory private speech and theory-of-mind

task performance in three separate cross-sectional studies (mean ages 49, 56, and 71 months). Correlations between these variables were computed with partialling for age and verbal ability. As predicted, private speech and SU performance were significantly positively related in the youngest sample, while the sign of the correlation shifted to negative in the oldest sample, in line with the assumption that children who were still using overt private speech at this point were relatively delayed in the process of internalization.

Viewing both EF and SU as mediated higher mental functions thus presents an alternative way of conceptualizing the developmental relations between these variables. Rather than attempting to account for the relation in terms of a strong executive component to SU tasks, or conversely an SU load on standard EF tasks, a combined interfunctional approach to EF and SU would see the development of both capacities as being driven by the internalization of dialogic, mediated interpersonal activity (Fernyhough, 1996; 2008; in press). That said, it also seems likely that EF and SU will be differentially sensitive to the varieties of social experience that children encounter, and that any social-environmental effects will vary in their influence depending on the age at which they occur. Indeed, it is axiomatic for the Vygotskian–Lurian functional systems approach that there will be shifting patterns of relations across age between the components of such systems (Vygotsky, 1934/1965). What the functional systems approach offers to future research in this area is the possibility of making sense of these differing patterns of interfunctional relations across the course of development.

The social brain

I have proposed that conceiving of EF and SU as functional systems may have important benefits for our developing understanding of these psychological processes. Firstly, such an approach will pay dividends for our theorizing about how more rudimentary forms of these capacities are augmented by developmental advances in other cognitive domains. Secondly, a conception of EF and SU as systems that rely crucially on semiotic mediation (predominantly through language) can shed new light on the observed developmental relations between these variables.

In the final section of this chapter, I suggest that the functional systems approach confers a third important advantage, specifically for our understanding of the neuroanatomical localization of EF and SU. One reason for rejecting a view of SU as a modular capacity is the lack of any compelling evidence that it is underpinned by a unitary neuroanatomical substrate (e.g., Apperly, Samson, & Humphreys, 2005). As Vygotsky and Luria showed, a functional systems approach requires us to rethink the question of how the complex systems that underlie apparently discrete psychological functions are localized in the brain. Among the most important implications are: (1) that the functional systems underlying EF and SU will comprise neuroanatomical components whose patterns of interrelation will alter throughout the course of development; (2) that patterns of localization in the adult brain will, for this reason, not necessarily provide an accurate model of how these functions are neurologically subserved in the developing brain; (3) that cortical development will involve bidirectional transactions between biological and social causes; and (4) that the cortical areas that subserve these functions will be differently organized to those areas not associated with mediated functional systems. I now consider each of these points in turn.

With regard to the changing interrelations between systemic components throughout development, one way of thinking about Luria's contribution in this respect is as a method of applying Vygotsky's ideas about functional systems to the problem of localization of functions within the brain (Wertsch, 1981). Recognizing that Vygotsky's insights about functional systems had allowed the transformation of psychology into "a science of *the social formation of natural phenomena*" (Luria, 1965, p. 389, original emphasis), Luria turned his attention to the problem of how to conceptualize the "material structure" of these phenomena. Luria proposed that Vygotsky's psychological concept of a functional system (which could be described without necessary reference to its neuroanatomical substrate) could be translated into the neurological concept of a "functional organ" (a concept derived from Leont'ev, 1981), the creation of which, "under the influence of social conditions" (Luria, 1966/1980, p. 33), created "a new means of unlimited development of the brain" (Luria, 1965, p. 391). In other words, new trajectories of brain development are made possible by the interaction of social and neurological causes in the creation of functional systems.

The result of this process, according to Luria, is the development of "a system of highly differentiated zones of the cortex working together, accomplishing new tasks by means of new 'inter-areal' relations" (Luria, 1965, p. 391). Furthermore, the psychological significance of these inter-areal connections will change throughout the course of development, meaning that only a "chronogenetic" (Vygotsky, 1934/1965), or time-sensitive, approach to the neurological instantiation of these systems would provide an accurate picture of their structure. From a modern cognitive developmental neuroscience perspective, therefore, the challenge for EF and

SU investigators is to specify which cortical regions work together at different stages of development in providing the neuroanatomical substrate for these functional systems.

A second implication that follows from the functional systems approach is that evidence for the localization of EF and SU in the adult brain will not necessarily provide a reliable guide to how these functions are instantiated during the course of development. Evidence that EF and SU dysfunction co-occur in some developmental and adult disorders, while showing patterns of double dissociation in others, has been held to support the view that these capacities are subserved by distinct but anatomically proximate neural areas (e.g., Saxe, Carey, & Kanwisher, 2004). Evidence from imaging studies of adults that the medial prefrontal cortex is heavily involved in reasoning about intentions (Frith & Frith, 2003) may thus be of only limited value in understanding the neurological underpinnings of SU in adolescence and earlier (Blakemore & Choudhury, 2006). Furthermore, Vygotsky's (1934/1965; Luria, 1965) arguments about the changing developmental significance of brain lesions are particularly relevant to attempts to bring neuroanatomical and neuroimaging evidence to bear on findings of EF and SU dysfunction in developmental disorders such as autism. A functional systems approach to these capacities would therefore seem to fit well with the growing recognition that evidence for modularity in adults cannot necessarily be taken to imply similar modularity in children and adolescents, and that the study of any particular psychological impairment in development will not necessarily provide clues to the neurological route to that impairment (Karmiloff-Smith, Scerif, & Ansari, 2003; Thomas & Karmiloff-Smith, 2002).

A third important implication for cognitive developmental neuroscientific approaches to EF and SU is that cortical development will be susceptible to bidirectional causal influences

between the biological and social worlds (Fernyhough, 2006). As noted above, Luria's position is particularly interesting in this respect. On the one hand, he is commonly credited with the idea that EF development is constrained by maturation of the prefrontal cortex. On the other hand, his writings on functional systems clearly indicate a role for social causation in brain development. Elsewhere (Fernyhough, 2006) I have proposed that Luria's position can be construed as a co-constructivist (Lindenberger, 2004) approach to development, in which the social influences the biological potentially as strongly as the biological influences the social[4]. With regard to the application of Luria's ideas to EF and SU development, the challenge is to specify how the mediation of cognition by cultural artefacts such as words in natural language allows the brain to "programme and re-programme itself" (Mecacci, 2005, p. 820) in the course of development.

The fourth implication is that these principles will apply to specific parts of the cortex, the organization of which shows fundamental differences with that of the brains of non-human animals (Mecacci, 2005). Consistent with his belief that Vygotsky's ideas had provided a solution to a fundamental problem in psychology, Luria argued that the implications of the functional systems approach for brain development could only be described in terms of a new principle of brain organization, in which social causes had their effects through the establishment of "extra-cerebral connections" (Vygotsky, 1960) between the brain and cultural artefacts such as signs. In Luria's words, "[s]ocial history ties those knots which form definite cortical zones in new relations with each other, and if the use of language… evokes new functional relations…,

[4] Broadly speaking, this position is congruent with emerging views of brain development as shaped and constrained in important ways by experience (e.g., Johnson, 2001; Mareschal et al., 2007).

then this is a product of historical development, depending on 'extra-cerebral ties' and new 'functional organs' formed in the cortex" (Luria, 1965, p. 391).

This organizational principle was held to apply exclusively to areas in the frontal and parietal lobes, regions attributed with particular importance in the emergence of the higher mental functions (Vygotsky, 1934/1965). Vygotsky's reference to these regions as "specifically-human" (ibid., p. 382) was not meant to deny the existence of these anatomical areas in other animals, but rather to underline the fact that it is these areas which, through the tying of extra-cerebral connections, acquire functions that are specific to human psychology. As noted, the prefrontal cortex is the area commonly associated with EF in studies of brain lesions (Luria, 1973). Lesions to the prefrontal cortex typically leave motor patterns, including speech production, intact, while specifically impairing patients' ability to benefit from the self-regulatory function of speech, such as the use of a self-directed verbal command in inhibiting behavior (Luria, 1981, Chapter 7). Rather than being necessary for the production of speech *per se*, the prefrontal cortex appears to play an important role in the interfunctional integration necessary for verbal self-regulation. To put it another way, when the neurological substrate of the functional system is damaged, the "extra-cerebral ties" which organize these forms of behavior are cut as well.

Conclusion

My aim in this chapter has been to show how close attention to Vygotsky's and Luria's writings on functional systems can pay dividends for our understanding of the developmental relations between EF and SU. Rather than becoming excessively concerned with establishing the direction

of causation between these two variables, future researchers may benefit from a view of development in both of these areas as being driven by the cognitive changes that result from a general transition towards semiotic mediation in the preschool years. In the process, it can be hoped that the view of these psychological functions as monolithic, indivisible entities will continue to lose ground to conceptions of both as complexes of constituent subsystems which demonstrate subtly patterned, dynamic interrelations throughout development.

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