Byron Review on the Impact of New Technologies on Children:

A Research Literature Review: Child Development

Usha Goswami

Professor of Education

Director, Centre for Neuroscience in Education

University of Cambridge

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BYRON REVIEW ON THE IMPACT OF NEW TECHNOLOGIES ON CHILDREN: A RESEARCH LITERATURE REVIEW: CHILD DEVELOPMENT

1. OVERVIEW

The field of cognitive development has changed dramatically over the last three decades. The field used to be dominated by Piaget's theory of cognitive development (Piaget, 1954), which conceptualised cognitive development as taking place within the head of the child, according to an internal programming of cognitive change based on states of "disequilibrium" between the child's mental states and the external world. Children were assumed to think and reason in a different way during each of the 4 stages of cognitive development (0 - 2 years, 2 – 7 years, 7 – 13 years, adolescence and adulthood). It is now recognised that children think and reason in the **same** ways as adults from early in childhood. Children are less efficient reasoners than adults because they are more easily misled in their logic by interfering variables such as contextual variables, and because they are worse at inhibiting irrelevant information. Logical skills improve as children get better at identifying irrelevant contextual variables and at inhibiting competing information; however note that adults also reason irrationally in situations when their contextual understanding is limited. The major developmental change during the primary years is the development of self-regulatory skills. The ability to self-regulate one's thoughts and actions is conceptualized as "metacognition" and "executive function", both discussed below. Hence cognitive development is no longer thought of in terms of "age bands", with

qualitatively different developments emerging at different ages. Cognitive development is experience-dependent, and older children have had more experiences than younger children.

Child development is today conceptualized as an essentially social process, based on incremental knowledge acquisition driven by cultural experience and social context. We have “social” brains. The importance of cultural processes were recognized by the theory of Vygotsky (1978, 1986), who also highlighted the key role of language for cognitive development. Vygotsky argued that cognitive development did not just happen in the brain of the individual child, but depended on interactions between the child and the cultural “tools” available for mediating knowledge. The main cultural “tool” (form of symbolic representation for knowledge translation, e.g., writing, pictures, maps) discussed by Vygotsky was language, which he conceptualized as a psychological “tool” for organizing one’s own cognitive behaviour (e.g., via “inner speech”). The perspective adopted in this review is that the inter-relatedness of social and cognitive processes in the child are fundamental. Cognitive development is argued to occur within three “foundational domains”, naïve physics (knowledge about the physical world of objects and events), naïve biology (conceptual knowledge about the world of animates, inanimates and artefacts) and naïve psychology (understanding and predicting people’s behaviour on the basis of psychological causation) (Wellman & Gelman, 1998).

The potential effects of the internet and video games appear most likely to impact on child development in the third domain, also called “theory of mind” or “social cognition”. This view would predict that the main impact of

new technologies will be on moral and pro-social development. However, cognitive developmental neuroscience is revealing powerful learning in all three foundational domains from the earliest months of life. Prior to language acquisition, sensory learning processes are critically important, playing a core role in the development of the cognitive system. For example, simple perceptual mechanisms such as tracking statistical patterns in visual or auditory input are the basis of understanding objects and how they interact, and of understanding and acquiring spoken language. Given the core role of sensory learning, what babies and young children see and hear via new media seem likely to impact sensory learning in fundamental ways. As there is currently almost no empirical evidence regarding the potential nature of this impact, the assessment of potential benefits or harms are expressed here as “potential effects” only and are speculations by the author. I include these speculations as I have been requested to extrapolate from existing empirical work to assess the potential effects of new technologies at different ages. Another way of attempting to predict the impact of new technologies on child development might be to think of new media as another cultural “tool” in Vygotsky’s sense of the cultural mediation of knowledge. From this perspective, the world as symbolically presented by the internet, YouTube-type sites or video gaming would be a cultural “tool” that can be used strategically to affect the child’s developing understanding of the world. I illustrate this where relevant throughout the review.

2. THE MAIN REVIEW

a. Learning and the Neuroscience of Learning

i. *Neural Statistical Learning*. Theories of cognitive development prior to the advent of cognitive neuroscience argued that infants must be born with "pre-knowledge" of complex skills like language. For example, Chomsky (1957) proposed a "language acquisition device", arguing that the brain came equipped with specialised innate knowledge about the general grammatical rules that all languages obey along with knowledge of permitted variations. Such theories were accepted because it seemed impossible that the brain could learn language or complex concepts like intentionality from environmental input alone. It is now accepted that very complex learning is achieved by the pre-verbal brain using statistical learning algorithms that have been discovered by research in machine learning (e.g., causal Bayes nets, explanation-based learning). This form of learning is unconscious and continues throughout life. Neural sensory statistical learning enables the brain to learn the underlying structure of experienced events, building "neural networks" (cohorts of interconnected simple on-off brain cells that activate together) to represent this information. Developmental cognitive neuroscience is revealing how powerful these learning mechanisms are, for example in rapid learning about social stimuli (like faces at 4 months, Farroni et al., 2002), and language at 3 months (Dehaene-Lambertz et al., 2006).

Importantly, information does not simply flow one way, from the senses to the neural networks. With experience of a particular stimulus, the brain begins to process abstracted dependencies rather than the pure physical

components. Representations of these abstracted dependencies (in layman's terms, a "stereotypical" expectation) then alters primary sensory processing. For example, when adults perceive illusory sounds in noise (i.e. a sound is perceived as continuous even though a noise occurs co-incidentally with a silent gap in the sound), the brain processes the abstracted dependencies of the basic properties of the sounds and the noise based on prior experience of these stimuli, rather than the acoustic properties of the actual sounds and noise currently being received by the sensory systems (Riecke et al., 2007). The brains of young infants also show sustained activity based on abstracted dependencies in the absence of sensory input, for example, when a hidden object disappears unexpectedly (Kaufman, Mareschal & Johnson, 2003). Perhaps the clearest current demonstration of how abstracted dependencies guide later sensory processing is in language acquisition. In learning the constituent sounds of language, we usually speak in terms of "prototypes" rather than stereotypes, but the core meaning is the same. Prototypes are generalized (abstracted) representations of a category of sensory stimuli, to which subsequently-encountered sensory stimuli can then be compared. For language, we can think of a prototypical "p" sound, or a prototypical "b" sound. However, a "p" sound made by a 40-year-old adult male and a "p" sound made by a 7-year-old girl are acoustically very different. Nevertheless, because the brain builds up a representation of a prototypical "p" as it encounters many different speakers, it will recognise both sensory stimuli as "p".

Potential Effects: In principle, these demonstrations of statistical learning processes mean that the kinds of sensory experiences that infants

and young children have will affect the “stereotypes” that the brain builds up. In fact, it is likely that similar “stereotypical” sensory learning occurs at all ages (because the abstraction of cross-modal dependencies from sensory input are a fundamental aspect of how our sensory systems function). Therefore, it can be *speculated* that if certain kinds of experience are frequent in the sensory input (e.g., violent events), the brain will develop normative or stereotypical representations of such inputs, and will then interpret new experiences in terms of these “stereotypes”. For example, if violent reactions to certain types of event (e.g., being threatened) are frequently observed, then the normative reaction to feeling threatened yourself would be a violent reaction. This reaction would be driven by unconscious experienced dependencies stored in the brain. Indeed, problems in interpreting the behavioural cues of others is characteristic of many children with anti-social behaviour and conduct disorders. These children frequently show a hostile “attribution bias”, tending to (mis)attribute anger to the actions and statements of others (Schultz et al., 2004). It is thought that such attribution biases reflect early (hostile and punitive) parenting experiences. Video gaming can also provide repeated experiences of hostile and punitive reactions by others, although without the social communication cues that would be present with real people. It is currently unknown whether such “virtual reality” experiences would lead to similar implicit sensory learning and generate attribution biases.

In terms of neural statistical learning, the infant brain is essentially learning about dynamic spatio-temporal structure across sensory modalities. Infants and young children spend a lot of time observing things happening in

the social context that they are in. Whether they are watching an “event” like someone fixing their dinner, the dog chasing a bird in the garden, or their siblings squabbling, they are learning about these events and about their underlying structure (e.g. physical laws like ‘containment’ – the potatoes are put inside the saucepan; information about ‘natural kinds’, such as dogs that move by running and birds that move by flying). This aspect of neural statistical learning demonstrates *experience-dependent* construction of the neural networks responding to the spatio-temporal information in the “events” experienced by the child, enabling the emergence of “event-general principles” such as the physical laws governing containment versus support, and information about different biological kinds such as dogs versus birds. However, machine learning studies show that statistical learning algorithms can be even more powerful than the variations of conditional probability explored so far with infants. Machine learning algorithms such as causal Bayes nets can learn causal structure from perceptual covariation data. Children and rats can do this too (Blaisdell, Sawa, Leising & Waldmann, 2006; Gopnik, Sobel, Schulz & Glymour, 2001). For example, specific perceptual features of two objects in a “launching” event (where object A impacts object B, causing it to begin to move) may vary, but spatio-temporal dynamics (and therefore causal structure, i.e., the fact that A causes B to move) will vary less. The perceptual “illusion” of causality during launching and other visual events noted by Michotte (1963) is one example of how perceptual covariation can yield causal structure (Scholl & Tremoulet, 2000). Most recently, it has been demonstrated that 6-month-old infants who watch geometric shapes (with eyes) that engage in self-initiated motion extract causal structure that

can be interpreted as “moral” causal structure (“helping” versus “hindering”). For example, in one scenario, the babies watched as a blue circle with eyes tried to move up a “hill” (piece of green apparatus), but repeatedly failed to get beyond a half-way “plateau”. A yellow triangle with eyes then appeared and “pushed” the blue circle on up the hill (or a red square appeared and pushed the blue circle back down the hill). The babies were then allowed to reach for both the “helper” and the “hinderer”. Twelve out of 12 babies reached for the yellow triangle (the “helper”, see Hamlin, Wynn & Bloom, 2007). The spatio-temporal structure of these objects and their “actions” was sufficient for the infants to interpret the movements as goal-directed actions with moral content. They all preferred the “positive” social acts.

The insights into causal structure that come from observing perceptual events are very powerful, but they are not always accurate. The level of knowledge that can be abstracted from spatio-temporal structure (perceptual causal information) about different entities has in important cases been transcended by modern physics and biology. A good example is the medieval “impetus” theory of motion, which has been supplanted by Newtonian physics (Kaiser, Profitt & McCloskey, 1985). According to the impetus theory of motion, every motion must have a cause. For example, we assume that if a ball is thrown by a person, it will move in a trajectory determined by the force of the throw, and will fall to earth when this force diminishes. However, if a ball is dropped by someone leaning from a moving train, no impetus appears to be involved - the ball appears to have fallen passively from the train. In this latter case, we assume that the ball will fall downwards in a straight line. In fact, however, Newtonian physics show that it falls forward in a parabolic arc. By

Newtonian physics, the moving carrier of the object imparts a force, just as if the object was being pushed from a table top. Importantly, when we learn Newtonian physics in school, we do not seem to replace the inaccurate "impetus" theory of motion given by our senses with the accurate Newtonian theory. Rather, brain imaging studies suggest that those students who have more expertise in physics are better at inhibiting the false inferences generated by the perceptual causal information and can thus reason more easily according to taught Newtonian principles (Pettito & Dunbar, in press). Studies such as these demonstrate that neural statistical learning about spatio-temporal structure can be over-ridden by taught knowledge, but only via effortful "inhibitory control".

Potential Effects: These experimental studies of causal learning mean that the causal structures that are abstracted from perceptual information are very powerful, and are difficult to inhibit. The brain automatically generates causal inferences from observed events, in accordance with probabilistic learning algorithms such as Bayes nets. Video gaming will provide extensive experience of certain kinds of spatio-temporal structures. It can be *speculated* that if observed events lead to the generation of causal structures that are undesirable (e.g., participating in video gaming could lead to a causal structure along the lines of "if someone acts to impede something that I desire, I should deal with the problem by shooting that person"), these may be difficult to inhibit even when taught morality is quite divergent ("if someone acts to prevent something that I desire, I should discuss with that person why they acted as they did and make my needs known").

Important Caveat: Empirical work on auditory statistical learning (language learning) by Kuhl and her colleagues has demonstrated that the statistical learning of prototypical sound elements of the language only occurs in the context of communicative interactions with caretakers. When experiments were set up to teach American English babies sound elements of Mandarin Chinese from watching television, they did not learn. In these experiments, 9 – 12 month old infants either played with Mandarin Chinese graduate students in naturalistic contexts, or watched videos of the same students and play contexts, with the video communicator "speaking" directly to the babies (Kuhl et al., 2003). Although the perceptual auditory "input" was thus equalised, and the video group were very interested in and attentive to the television screens, these babies did not learn Mandarin Chinese sounds. Kuhl concluded that social interaction plays a critical role in perceptual statistical learning (see also Kuhl, 2004). Whether this finding for auditory statistical learning would generalise to visual statistical learning is not known (for example, to the visual spatio-temporal dynamics experienced during video gaming). Also, the goal of language is communication, so in this sense learning language may be a "special instance" of neural statistical learning, where face-to-face interaction is critical for communicative learning to occur.

ii. *Learning by Imitation*. Learning by imitation is another critical form of early learning. Here the infant or child reproduces observed actions as a way of understanding them better. The importance of reproducing observed actions was core to Piaget's theory of the "sensory motor stage" (0 – 2 years) of cognition. Piaget emphasised the importance of repetitive actions to babies, for example the repeated dropping of a rattle or bottle in order to watch its

trajectory (and to watch the caretaker retrieve it!). Piaget argued that intentional imitation emerged at around 18 months, but it has since been shown that babies as young as 1 hour old can imitate facial actions (Meltzoff & Moore, 1983). In Meltzoff and Moore's classic 1983 study, adults modelled gestures like tongue protrusion and mouth opening in a quiet environment, and the infants reproduced these gestures. By around 9 months, babies can learn how to manipulate novel objects such as experimenter-built toys by watching others manipulate them (Meltzoff, 1988). Older babies can even imitate intended acts which are never observed. Meltzoff manipulated a number of novel events (e.g., inserting a string of beads into a cylindrical container) so that the adult demonstrator accidentally failed to demonstrate the event (e.g. fumbled the beads so that they missed the opening). The observing infants took the beads and put them into the container successfully (Meltzoff, 1995). Empirical studies such as these show that the infants are going beyond what is observed and are attributing goals and intentions to the demonstrator (see also Tomasello and colleagues, e.g. Carpenter, Call & Tomasello, 2005). Understanding the goals of another person transforms their actions into purposive behaviour (Gergely et al., 2002).

Vygotsky argued that imitation, particularly in the form of pretend play, was critical for cognitive development. He argued that during infancy and toddler-hood, actions were dominant over meaning, as children could do more than they could understand. Via pretend play, children could make actions dominant over meaning. One example was a child who wishes to ride a horse, who stamps the ground and imagines herself riding a horse, rather than performing the actions required to ride a real horse (Vygotsky, 1978).

Vygotsky argued that the world of the imagination fulfilled a crucial psychological function in development, enabling children to detach themselves from reality and to act in a purely cognitive realm, rather than relying on motivational incentives supplied by external things:

"Action in the imaginative sphere, in an imaginary situation, the creation of voluntary intentions, and the formation of real-life plans and volitional motives - all appear in play and make it the highest form of preschool development … From the point of view of development, creating an imaginary situation can be regarded as a means of developing abstract thought.." (Vygotsky, 1978, p. 102 - 103).

Potential Effects: Learning by imitation enables children to act out observed events, and thus to gain a deeper understanding of them. Children usually imitate what they have seen, whether this is in the physical realm (e.g., causing objects to fall) or in the social realm (e.g., playing at being the mother looking after the baby). It can be *speculated* that children will also imitate what they see on the internet on sites like YouTube and during video gaming in their play outside these contexts. This may be particularly likely when they have not understood events that they have seen or have participated in, for example during a virtual reality experience. Hence it can be *speculated* that the nature of these experiences may be very important for development. For example, if children have participated extensively in violence-based games, they may produce more violent imitative play.

iii. *Learning by Analogy*: In learning by analogy, "we face a situation, we recall a similar situation, we match them up, we reason, and we learn" (Winston, 1980). We may decide whether a dog has a heart by thinking about

whether people have hearts (young children use “personification analogies” to learn about biological kinds, see Inagaki & Hatano, 1988), or we may solve a mathematical problem about the interaction of forces by using an analogy to a tug-of-war (young children use familiar physical systems to reason about unfamiliar ones, see Pauen, 1996). Reasoning by analogy has usually been measured in children aged 3 years or older (see Goswami, 1992, 2001, for reviews), but can also be demonstrated in infancy. However, so far, analogy has not been found in the animal kingdom, suggesting that it is especially important for *human* learning.

One of the earliest demonstrations of analogical transfer by infants came from an experiment with 3-month-old babies reported by Greco, Hayne and Rovee-Collier (1990). Rovee-Collier and her colleagues used an experimental paradigm in which babies learned to kick their legs to activate an attractive mobile. Memory for this causal contingency could last for months, as long as a reminder cue was given when retrieval of the memory was tested. For example, infants who had been trained with a mobile made of 5 hanging cubes could be given a mobile shaped like a butterfly perched on a ring as a reminder cue (Greco et al., 1990). The butterfly mobile was rated by adults as highly perceptually dissimilar to the cubes mobile, but it acted as a perfectly good retrieval cue for the infants. It was functionally analogous to the original mobile. Similarly, Brown has shown that 2-year-olds will use analogies based on functional relations to understand physical systems (Brown, 1989). Early analogies tend to depend on functional or causal relations, but once language is acquired analogies can be quite abstract (e.g. 3-year-old children deciding how animals can evade predators by using different forms of mimicry, see

Brown, 1989). The use of analogy depends crucially on the knowledge base. Children can only use analogies based on familiar relations, relations that they have experienced or that they understand.

Potential Effects: Learning by analogy is ubiquitous in human cognition. One aspect of new technologies might be to expose children to relational systems that they might otherwise be unfamiliar with, or might otherwise not experience until later in development. Children would then be likely to make analogies to other situations on the basis of what they have learned from the internet or from video gaming. These analogies could be positive (e.g. learning how to care for animals from playing a zoo-keeping game) or negative (e.g. learning how to victimize someone from playing a war game).

b. Knowledge Construction

The preverbal neural perceptual statistical learning discussed in section (a), supplemented by learning by action, imitation and analogy, enables knowledge construction by children in the three foundational domains of naïve physics, naïve biology and naïve psychology. Simple perceptual cues such as motion can deliver information about physics and biology. For example, if something moves in a very regular and predictable way, it is likely to be mechanical (a car), whereas if something moves erratically and can self-initiate motion it is likely to be biological (a fly). This was reviewed in section (a) above in terms of the brain making perceptual analyses of the dynamic spatial and temporal behaviour of objects. These perceptual analyses can give information about whether something is an agent, an artefact or a plant, for example.

i. *Naïve Physics*. In developing knowledge referred to as “naïve physics”, infants and children are constructing a causal framework for explaining the behaviour of objects. Cross-modal information from our sensory systems yields a lot of data about the laws governing physical interactions between objects. For example, adults who watch a computer display in which two identical disks move from opposite sides of the screen towards each other, and then past one another at a constant speed, perceive them as streaming through one another. However, if a sound is presented at the moment when the two discs coincide, the discs are perceived as bouncing off one another (Sekuler, Sekuler & Lau, 1997). Six-month-old babies experience the same cross-modal illusion of bouncing (Scheier, Lewkowicz & Shimojo, 2003). This suggests that the brain processes the sensory information that we use to explain the behaviour of objects in the same way across the lifespan. In naïve physics, experiments show that sensory perception organises itself fairly rapidly around a core physical framework representing the arrangement of cohesive, solid, three-dimensional objects (e.g., Spelke, 1991). 3-D objects are understood to interact via mechanical relations such as *pushing*, *blocking* and *support*.

This understanding of the physical world is constructed by the infant and young child via perceptual causal analyses that are part of how the brain processes sensory information, and also by *action*. Once infants and young children have the motor abilities to manipulate objects by themselves, knowledge construction in the physical domain is accelerated by the manipulation of causes and the observation of effects (e.g., pulling the plug when your carer is doing the vacuuming). The ability to intervene in causal

systems enables invalid inferences to be ruled out. Children use causal principles such as temporal order, and real world knowledge about likely causes and effects (e.g., that a switch is probably a cause of something), as a basis for inferring the causal structure of physical events. Experiments have shown that these causal principles are already being used by 2- and 3-year-olds (e.g., Bullock et al., 1982; Shultz, 1982).

Information gained through action is central to the development of the core explanatory frameworks that underpin cognitive development. Piaget's theory of child development recognised the importance of action for learning (e.g., Inhelder & Piaget, 1958), because his theory of cognitive development was constructivist. Piaget argued that sensory-motor knowledge became thought, as it was "re-represented" on the mental plane. Modern cognitive neuroscience suggests that action representations are indeed embedded in our linguistic concepts (e.g., Hauk, Johnsrude & Pulvermuller, 2004, showed that when we read a word like "lick", there is brain activation in the motor system that controls tongue movements). However, it is not clear that there is any "re-representation" of sensory-motor knowledge. Rather, as all knowledge in the brain depends on highly distributed neural networks, with brain cells in many systems active together (e.g., motor systems, sensory systems, the language system), it is more likely that knowledge constructed via sensory-motor experiences is augmented by linguistic and taught knowledge. Modern developmental psychology has also shown that physical knowledge and causal knowledge develop much earlier than envisaged by Piaget (see Goswami, 2008).

Potential Effects: The importance of action for knowledge construction means that new media that require active responding by the child to realistic 3-D objects are likely to lead to deeper learning than media requiring passive viewing. It can be *speculated* that the repetitive actions required in some video gaming (e.g. continual shooting of “enemies” as they appear in your path) would cause deeper learning of causal structure. It can therefore be *speculated* that the perceptual causal learning discussed above in (a) (i) with respect to sensory learning of causal structures like “respond to any threat by shooting” could be enhanced by video games that require active responding. Also of note is the *anecdotal* evidence that active video gaming can be very addictive to the (male) teenage brain. I can think of no biological reason for this, but it would be an interesting topic for research.

ii. *Naïve Biology*. Knowledge referred to as “naïve biology” is essentially conceptual knowledge, or knowledge about the kinds of entity in the world. The core distinction is between “natural kinds” (people, animals, plants) and artefacts (vehicles, furniture, buildings). Infants begin developing knowledge of this distinction from simple perceptual cues like movements and sounds. For example, experiments using “point light displays”, which remove all attributes except motion, show that 3-month-olds can distinguish animals from vehicles on the basis of motion alone (Arterberry & Bornstein, 1997). Point light displays are created by putting points of light on key joints (animals) or intersections (vehicles) of objects, and then filming them as they move. When the points of light are viewed against a plain background, a strong impression of an animal moving or a vehicle moving is experienced by the perceiver. Babies appear to experience this as strongly as adults. Perceptual

similarity between entities is another important source of information for the naïve biologist. When things look similar, this can be a reliable indication that they share core properties. For example, plants look similar to other plants, and share core properties such as cellulose. When perceptual information is not reliable, even 2-year-olds prioritise structural similarity (e.g., having cellulose) in categorising biological kinds. It appears that young children have learned that “insides” are more important than “outsides” from their observations of the world. For artefacts, *function* is judged to be the most important shared feature (e.g. something can be “a seat” as long as it can be used to sit on). As language is acquired, labels become another important cue to structural and functional similarity. For example, consistency of labelling (e.g., “chair” for highchair *and* rocking chair, “dog” for alsatian *and* dachshund) denotes shared categories.

In constructing biological knowledge, therefore, as in physical reasoning, infants and young children are using perceptual temporal-dynamic structure, the connection of causes and effects, and perceptual similarities and analogies to develop their understanding of the conceptual world around them. Experiments in cognitive neuroscience (with adults) suggest that the brain codes concepts in terms of the sensory modalities that are active when the concepts are being directly experienced. Following repeated experiences of a particular concept, what is common across instances will be activated more strongly than what is not. Hence for events and actions (physical reasoning), causal structure will be strongly represented. For object categories, information about the structure and action of biological entities (can fly) or artefacts (needs to be switched on) will be strongly represented.

The brain also keeps track of which neural networks tend to activate together. Object categories have very distributed representations, and any category is represented by activation in multiple modalities at the same time. For example, when a child activates the concept “fish”, knowledge about how fish look, how they move, what they smell like and what they feel like to touch are simultaneously active and together constitute the child’s conceptual knowledge about fish. Neurally, we do not seem to have amodal or abstract “concepts” held in a separate storage system (semantic memory). Instead, knowledge of the world seems to be held in lots of different parts of the brain (Barsalou et al., 2003).

Potential Effects: Developmentally, therefore, as in constructing knowledge about physical systems, there are no age-bands in which we can specify different types of conceptual or physical knowledge. Rather, development comprises incremental learning based on experience. This incremental learning gradually turns a child from a novice to an expert. Gaining expertise is usually related to age, but not always. For example, there are 4-year-olds who are experts on dinosaurs, who know much more about dinosaur habitats, typologies and feeding patterns than many adults. Motivation to learn about a particular conceptual field can drive a child to seek out more information about this field, and lead to earlier expertise. It can be *speculated* that one very positive impact of new technologies such as the internet is in enabling access to knowledge. This is likely to be more important for older children, who can self-regulate their own learning (see section [e] below). An issue to be considered is how the child can judge the veracity of information available over the internet.

iii. *Naïve Psychology*. In developing the knowledge referred to as "naïve psychology", infants and children are constructing a causal framework for explaining the behaviour of people. They are learning that the actions of other agents will depend on the knowledge and beliefs held in their *minds*, and that this knowledge and these beliefs may differ from the knowledge and beliefs that the child holds in her/his own mind. Naïve psychology poses a bigger challenge in terms of child development, as aspects of mind such as desires and beliefs are not perceptually observable entities. Instead, the contents of the mind (and indeed, the existence of the mind) have to be inferred from goal-directed human behaviour.

Learning by imitation is an important source of learning about psychological causation. For example, Meltzoff (2002, 2007) has argued that the recognition of self-other equivalences demonstrated by infant imitation may function as a "like me" analogy. He suggests that by connecting the visible bodily actions of others with their own internal states, infants can feel what it is like to do the act that was seen. The recognition of self-other equivalence in action then enables infants to realise that others have perceptions and emotions that are also "like me". This provides one foundation for understanding the actions, goals and psychological states of others. Perceptual information is also important, in particular the observation of goal-directed behaviour. Experiments show that even 3-month-olds can interpret the behaviour of others as goal-directed (Sommerville, Woodward & Needham, 2005). Goal-directed action plays a special role in the development of psychological understanding, because the interpretation of the goals of other agents requires some insight into their *intentions*. Infants also follow

gaze, which is important for inferring intentionality, and engage in joint attention, which they can themselves initiate by pointing to objects of interest from around 10 months. Thus simple mechanisms such as gaze following, watching goal-directed actions and imitation are the foundations from which infants construct psychological knowledge.

However, whereas further cognitive development in the foundational domains of naïve physics and naïve biology depends on veridical primary representations (i.e., the brain must represent what is actually there in the external world), cognitive development in the foundational domain of naïve psychology depends on the representation of mental states, which are not objectively “there” in the external world. To develop a deeper understanding of mental states, shared social activities are critical. The primary social activities are pretend play and family discussion of feelings and emotions. Pretending can be solitary, as when a child plays at holding a tea party for teddy, and the main developmental function of this type of pretending is thought to be to enable the manipulation of the child’s own cognitive relations to information (Leslie, 1987). For example, if a leaf is used as teddy’s plate and twigs are used as his knife and fork, then the child is suspending the veridical sensory status of the leaf as a leaf, and substituting an imaginary cognitive status as a plate. Leslie argues that this kind of pretending marks the beginning of a capacity to understand cognition itself - to understand thoughts as entities. Lillard (2002) has discussed this in terms of “quarantining” – quarantining off what is pretend from what is real. However, much pretend play occurs with other children, in particular socio-dramatic pretend play. This kind of imaginary play has an important developmental function in helping the young child to

understand mental states such as desires and beliefs as entities that can be reasoned about and used to predict behavior. Pretend play and role play provide a context in which discussions about feelings, thoughts, and desires take place, and this discourse about mental states has a developmental function in enhancing understanding. As noted by Lillard (2002), as children get older less time tends to be spent in actual play, and more and more time is spent in negotiating the plot and each other's roles. This shared discussion is very important for the development of social cognition, and is considered further below in the section on moral and pro-social development (section f).

Social cognition is currently an active area of research in developmental cognitive neuroscience. Interest has focussed on a neural system called the "mirror neuron system", which is known to be important for action and imitation. Mirror neurons were discovered in monkey research on the representation of action. These neurons were found to become active when the monkey performed object-directed actions such as tearing, grasping, holding and manipulating. Furthermore, the same neurons became active when the animal observed *someone else* performing these actions, such as someone else tearing paper. Mirror neurons were even activated by the sound of an action, such as the sound of paper ripping (Rizzolatti & Craighero, 2004). Rizzolatti and his colleagues pointed out that an action implies a goal and an agent, and therefore argued that mirror neurons may play an important role in understanding intentions. It has since been shown that mirror neurons are active during imitation, and are only activated by biological actions (e.g., a human hand grasping, Tai et al., 2004). Mirror neurons are not activated by mechanical actions such as a robot hand

grasping, and Meltzoff has shown that babies will imitate actions on objects made by human hands but not identical actions made by mechanical hands (Meltzoff, 1995). It is therefore thought that the mirror neuron system may be a neural substrate for understanding the actions and internal states of others. Interestingly, children with disorders of social cognition such as autism appear to have very little mirror neuron activity (Dapretto et al., 2006). It is thus *speculated* that the mirror neuron system plays a role in the development of empathy. “Cognitive” empathy is impaired in autism, whereas “emotional” empathy is impaired in anti-social behaviour and conduct disorders (Blair, 2008).

Potential Effects: Although we will consider social cognitive development further below in section (f), the way in which the brain represents the goal-directed actions of biological versus mechanical agents and uses the former as a basis for understanding psychological causality appears relevant to video gaming. What appears to be crucial in terms of developing an understanding of mental states is whether the agent in a video game is perceived as a biological entity or not. One important perceptual feature is whether a cartoon figure has eyes or not. Even geometric shapes are perceived as animate entities if they have eyes, as shown by the experiment by Hamlin et al. (2007) discussed above. Experiments to test whether the mirror neuron system is activated by “unreal” cartoon characters that have eyes are not available (but my guess is that mirror neurons would be activated, as having eyes is a critical biological feature and all the motion cues would support a biological interpretation). Another crucial feature in terms of the effects that video gaming or internet viewing might have on social-

cognitive development is quarantining – whether the child can “quarantine off” what is pretend from what is real. Younger children in particular have difficulties in separating pretence from reality, especially for scary pretence (e.g., Harris, Brown, Marriott, Whittall & Harmer, 1991). It can be *speculated* that video gaming will have stronger developmental effects when a child has difficulties in quarantining experiences in the game as pretend experiences rather than real experiences. This could be either beneficial to psychological development (e.g., a game requiring altruism) or detrimental (e.g., a game requiring the repression of empathy so that the enemy can be killed).

c. Language and Talking

Although language acquisition per se was not requested as part of this review of child development, it is important to discuss the symbolic aspects of language development because of the central role played by language in thinking and self-regulation. As argued by Vygotsky (1978, 1986), children use language to reflect upon and change their own cognitive functioning. Language underpins the development of “metacognition” and “executive function” skills (section e), enabling children to respond psychologically to a symbolic system held in their brain rather than to concrete events in the “here and now”. Symbol systems like language also enable explicit self-regulation, as humans can use language intentionally to organise and improve their own cognitive performance.

Words are symbols because they refer to an object or to an event, but they are not the object or the event itself. Symbols allow children to disconnect themselves from the immediate situation. Vygotsky (1978) argued

that language is the core symbolic system underpinning human cognitive activity. He pointed out that when children were put into problem-solving situations, they

"..not only act in attempting to achieve a goal, they also speak. As a rule, this speech arises spontaneously and continues almost without interruption throughout [the experiment]. It increases and is more persistent every time the situation becomes more complicated and the goal more difficult to attain. Attempts to block it .. are either futile, or lead the child to 'freeze up'" (Vygotsky, 1978, p. 25).

Vygotsky characterised talking as another kind of "action" for attaining goals – in young children, talking can be goal-directed behaviour. Word learning (symbol learning) is exponential in early childhood, with around 10 new words per day acquired by 2-year-olds. Research conducted with American children showed that median English spoken vocabulary size was 55 words by 16 months of age, 225 words by 23 months, 573 words by 30 months, and 6000 words by age 6 (Fenson et al., 1994). By the age of 6 years, average comprehension vocabulary is 14,000 words (Dollaghan, 1994). Another study showed that middle class toddlers hear an estimated 5000 – 7000 utterances a day (Cameron-Faulkner et al., 2003). However, there are large SES differences in how much language children hear. In another US study, Hart and Risley (1995) estimated that children from high SES families heard around 487 utterances per hour, compared to 178 utterances per hour for children from families on welfare. This meant that by the time they were aged 4 years, the high SES children had been exposed to around 44 million utterances, compared to 12 million utterances for the lower SES children. It

has not been investigated whether this affects symbolic development, but given that the brain learns incrementally by extracting patterns from the input, it can be *speculated* that this difference in verbal input would have some effects on linguistic and symbolic development.

According to Vygotsky's theory of child development, cognitive development depends on interactions between the child and the psychological (or cultural) tools available for mediating knowledge. Language is one such cultural tool, its central use is social communication, and adults most typically mediate interactions with language. Adults do correct children's use of language, but they do this informally, by reformulating incorrect utterances rather than by overt correction (e.g., Child: "I want butter mine." Father: "Okay, give it here and I'll put butter *on it*." Child: "I need butter *on it*."; Chouinard & Clark, 2003).

Whereas Piaget focused on how the individual child constructed knowledge for herself, Vygotsky argued that knowledge originated in socially meaningful activity shaped by language. Language enabled children to disconnect themselves from the immediate, concrete situation and to generate possibilities and plans for solving problems. Language was also thought to play a role in controlling the child's own behaviour – by speaking of her intentions, the child guided her actions. Once speech became internalised ("inner speech"), language could also play a self-guiding role in cognitive and emotional responses. Hence language enabled the self-regulation of cognition, emotion and action. For Vygotsky, once the child was verbal, language and thought were inevitably interdependent. Language also enabled the child's field of attention to embrace "a whole series of potential perceptual

fields that form successive, dynamic structures over time" (Vygotsky, 1978, p. 36). Hence the ability to combine past and present "perceptual fields" via language made possible reconstructive memory. Vygotsky emphasised that children gained access to the psychological tool of language because of the social/cultural context in which they developed, and because of face-to-face communications and interactions with others.

Potential Effects: Social interactions around language are critical for child development, and it seems likely that internet use and video gaming, which are usually solitary activities, reduce the opportunities that children have for social interactions around language. It can be *speculated* that any such reduction will have negative developmental effects on linguistic development and on symbolic development, and thereby possible knock-on effects on children's development of self-regulation skills and inhibitory control. It can also be *speculated* that such effects might vary by social class.

d. Memory

Typically, memory is understood as the ability consciously to retrieve autobiographical happenings from the past – the "reconstructive" memory discussed by Vygotsky (1978) that is facilitated by language. This form of memory may be unique to the human species. Another form of retrievable memory is semantic memory, our generic, factual knowledge about the world, for example knowledge of concepts and language. These forms of memory are called *explicit* memory, as they consist of knowledge that can be brought consciously and deliberately to mind. Humans also have implicit or *procedural* memories. Implicit memories are unconscious memories of the kind discussed

in section (a) regarding neural statistical learning, and can be demonstrated when there are changes in human performance that do not involve conscious memory content. For example, skill learning (riding a bike), habit formation (twirling one's hair), associative learning (salivating to the smell of fresh bread) and habituation ("tuning out" the ticking of a clock) are all forms of implicit memories.

Experimental data show that the different forms of implicit memory are well-developed in young children. For example, one form of implicit memory is recognition memory, the ability to recognise that something is familiar and has been experienced before. Infants and young children have good recognition memory. In one classic experiment, Brown and Scott (1971) showed children aged from 3 - 5 years a series of 100 pictures. In a recall test, they found that the children could recognise which pictures were familiar on 98% of trials. Explicit memories develop more slowly. This is because children (and adults) do not record events that occur in their lives into their memories in a verbatim fashion, like a video camera. Rather, as originally demonstrated by Bartlett (1932), children and adults construct memories. This process of construction depends on prior knowledge and personal interpretation.

The importance of prior knowledge means that very young children may not structure their experience in memorable ways, particularly if they do not understand particular experiences (e.g., someone dying). The formation of accurate memories also depends on how much sense the memoriser can make of the temporal structure of their experiences. Younger children have less understanding of temporal structure. Very young children are also still acquiring language, and as discussed above, language is important for

memory. Language helps us to rehearse our own experiences or to recount them to someone else, and experimental research has shown that engaging in verbal narratives helps to establish memories more firmly. All of these factors help to explain why we retain very few memories of our earliest years (“infantile amnesia”). Very young children lack the temporal, causal and verbal frameworks necessary for constructing explicit memories. Clearly, the development of memory cannot be isolated from the development of other cognitive processes.

Abstract knowledge structures for describing the temporal and causal sequences of events are referred to as “scripts”, and by 2 years children are creating scripts for the routine events of their childhoods such as ‘having a bath’ or ‘going shopping’ (e.g., Nelson, 1986). It has been argued that one reason that routines are important to young children is that they play a salient role in memory development, making the world into a predictable place (Nelson, 1988). Each script is essentially a “generic” or “abstract” knowledge structure that represents the temporal and causal sequences of events in very specific contexts.

Experimental research also shows that the ways in which parents interact with their children influences the development of scripts and of memories in general. Parents who ask children to elaborate on shared past events with questions such as "Where did we go yesterday?", "Who did we see?", and "Who was there with us?" have children with better memories (Hudson, 1990; Reese, Haden & Fivush, 1993). Such questions may help young children to organise experienced events into the correct temporal and causal order, and to learn which aspects of events are the most important to

recall. In fact, Reese et al. (1993) found that there were two distinct maternal narrative styles, and these styles were related to the ways in which children recalled their own past experiences. Mothers who consistently elaborated on the information that their child recalled and then evaluated it were said to have “elaborative styles”. Mothers who tended to switch topics and who provided less narrative structure, and who seldom used elaboration and evaluation, were said to have “non-elaborative” styles. Children observed remembering family events at 40 and 46 months who had mothers judged to have elaborative styles remembered more information when tested at 58 and 70 months. Adult-guided reminiscing may help the child to learn more sophisticated forms of narrative organisation.

Nelson and Fivush (2004) argue that the human ability to create a shared past allows each individual entry into a community or culture, in which individuals “share a perspective on the kinds of events that make a life and shape a self” (p. 506). They also point to important cultural differences in how shared reminiscing provides children with information about how to be a “self” in their culture. For example, the self-definition and self-story of the individual is seen as more important in modern Western cultures than in Asian cultures. Van Abbema and Bauer’s (2005) prospective longitudinal study found that whereas younger children used discussion of the past to develop understanding of their family and their own role within it, older children talked about the autobiographical past to cement relationships with peers. Talking about the past with family and friends leads to the development of a personal history, facilitating the emergence of the “autobiographical self”. Children who have had very disorganised or hostile experiences of parenting appear to

construct a disorganised self-concept, so that there is no central and effective experience of “self” (e.g., Fonagy & Target, 1997). This is discussed further below in section (g).

Potential Effects: The importance of social and cultural experiences for memory development, and the importance of the elaborative discussion of these experiences with caretakers for optimal retention, suggests that what children learn and remember from the internet and video gaming can be enhanced by shared reminiscing with adults, older siblings or even peers. It can be *speculated* that the frequent experience of events with a particular temporal and causal structure, for example via video gaming, will lead to the formation of scripts for those events that make them part of normative experience (generic knowledge structures). However, without elaboration by parents or other companions who have a grasp of the temporal and causal structure of the events, it is possible that the memories formed may be less coherent. It can also be *speculated* that if these experienced events encapsulate scripts that are not valued by the child’s culture (e.g., gang wars), then experiences that are undesirable may be internalised. Finally, it can be *speculated* that frequent active experience of violent video gaming could have negative effects for the development of the “autobiographical self”. If interactive video gaming requires role playing in which the repression of empathy for others and violent responding is glorified, and if being successful in such games is endorsed by the peer group, then it can be *speculated* that these attributes might be incorporated into the autobiographical self.

e. <u>Executive Function, Metacognition and Self-Regulation</u>

The aspects of child development discussed so far, for example knowledge construction, language acquisition and memory, do not show marked functional differences with age, although of course expertise increases with age because learning is incremental. Distinctive age-dependent differences in how the brain reasons and learns are not found, which is why Piaget's theory that children think and reason in qualitatively different ways at different ages is no longer accepted. However, executive function and self-regulatory skills do show marked differences with age during the primary school years, with particular developmental changes between the ages of 3 and 7 years (e.g. Hughes, 1998; Carlson & Moses, 2001). Skills such as attentional flexibility, inhibition (of thoughts, emotional responses, or actions) and metacognition (insight into your own cognitive performance) become very important in explaining individual differences in children's cognitive development. Gaining self-regulatory skills and reflective awareness of one's own cognition are major developmental achievements, and are still unfolding during adolescence.

Vygotsky's (1978, 1986) theory ascribed language a key role in the development of self-regulation. He saw internalised language ("inner speech") as fundamental in cognitive modulation. Inner speech was hypothesised to organise the child's internal cognitive activities and to regulate the child's external behaviour. Cognitive neuroscience research shows that an area of the brain called the frontal cortex plays a key role in self-regulation, in particular via inhibition. This brain region appears to govern the ability to inhibit particular actions in the light of new knowledge, and to shift attention flexibly as updating is required. Adults with damage to frontal cortex show

characteristic “executive errors”, such as perseverative inappropriate behaviour and an inability to switch attention between tasks. The frontal cortex continues to develop into the early twenties.

The development of self-regulation or “executive function” is usually measured by tasks such as delaying the gratification of a desire, or inhibiting responding to a very salient stimulus (Carlson & Moses, 2001). For example, Kochanska, Murray, Jacques, Koenig and Vandegeest (1996) investigated 33-month-old and 46-month-old children’s ability to delay gratification of a desire in a longitudinal study. In various experiments, the children were tempted to violate particular standards of behaviour (e.g. they were required to hold a sweet on their tongues for up to 30 seconds before eating it). The various tasks used formed an “inhibition control” battery. Girls were found to outperform boys at both toddler and preschool ages, and older children were found to have better inhibitory control than younger children. A typical inhibitory task involving conflict between salient responses is the “day/night” task. Here children are shown cards depicting either the sun or the moon. When they see a picture of the sun, they have to say “night”. When they see a picture of the moon, they have to say “day”. Performance in such “conflict” measures of inhibitory control also improves from 3 to 7 years. Efficient inhibitory control is obviously required for effective self-regulation. As well as language acquisition, important drivers for the development of self-regulatory skills are non-verbal ability, family dynamics and working memory. The role of families is discussed below in section (f). Working memory refers to the temporary storage of information while it is being processed for use in other cognitive tasks, such as reasoning. Working memory capacity increases with

age, and increased capacity is thought to be important in enabling the child to keep multiple perspectives in mind when effortfully controlling their cognitions, actions and emotions.

Developments in self-regulatory skills enable children to inhibit certain thoughts or actions when it is advantageous to do so, and to develop conscious, strategic control over their thoughts, feelings and behaviour. Poor self-regulatory control is characteristic of children with attention-deficit hyperactivity disorder (ADHD) and of children who exhibit anti-social behaviour and conduct disorders. Developmental aetiology is complex, but for ADHD is thought to involve organically-based difficulties with sustained and selective attention and impulse control. For anti-social behaviour and conduct disorders, primary impairments in social cognition and language development that arise from dysfunctional family relationships are thought to impair the development of self-regulatory skills.

Potential Effects: Most research to date has been descriptive, documenting the development of self-regulatory skills rather than exploring how these skills might be enhanced in young children. The hallmarks of poor self-regulation are cognitive inflexibility (e.g., children find it difficult to move back and forth between tasks, or to “set shift”), and an inability to inhibit responding (e.g. children cannot prevent themselves repeating now-inappropriate responses). It can be *speculated* that video gaming could have positive effects on both these core aspects of self-regulation. Video games are already known to improve skills such as visual attention (see Johnson review), and depending on the demands of the particular game, could potentially improve cognitive flexibility and inhibitory control. For example,

games that require the child to hold multiple perspectives in mind simultaneously, to plan a sequence of actions, or to stop themselves making certain responses, may enhance these components of self-regulation. It is currently unknown whether children with immature skills in these areas would simply be unable to meet the cognitive demands made by such games, or whether practice with the games would enable development. It is also unknown whether such skills would transfer beyond the gaming context (for example, whether the ability to plan a sequence of actions to find a hidden treasure in a video game would mean the child became better able to plan how to study for an exam).

f. Pro-social Development and Moral Development

Some of the origins of pro-social development were discussed earlier (section b) when reviewing knowledge construction in the area of psychological causation ("naïve psychology). It was shown that simple mechanisms such as gaze following, imitation and watching goal-directed actions led to the development of intention reading skills, and gave the child an insight into the existence of mental states. Understanding the mental states of others enables the child to predict their behaviour on the basis of their beliefs, emotions and desires. This is also referred to as developing a "theory of mind". Another important factor in developing a theory of mind discussed earlier is pretend play. As noted earlier, socio-dramatic pretend play and role play are particularly important. Youngblade and Dunn (1995) pointed out that pretend play with siblings differs from pretend play with the mother, as siblings are more likely to be actors in the drama themselves. This is also true of

children's friends. Pretend play between friends makes high demands for imaginary and co-operative interaction. In one study of 4-year-olds and their best friends, Hughes and Dunn (1998) found that the rate of mental state talk between the dyads during pretend play predicted later performance on theory of mind and emotion understanding tasks. Dunn and Cutting (1999) showed that the nature of interactions with friends had differential effects on the development of a theory of mind. In their study of 128 4-year-olds, dyadic play was rated for the frequency of co-operative pretend play, co-ordinated play, conflict, communication and amity. Dunn and Cutting found that while some children shared an imaginary world together with great skill and enjoyment, others rarely created shared pretence, preferring to engage instead in boisterous games or even "shared deviance" (e.g., killing flies together). It was shared pretence that predicted theory-of-mind development. Maternal education and family background also made important contributions to better performance.

A third factor that is important for the development of a theory of mind is experiencing rich linguistic communication about feelings, emotions and behaviours, usually in a family context. The importance of family discussion for the development of adequate social understanding is shown by the marked delays in theory of mind shown by deaf children who are not native signers. Most deaf children are born to hearing parents, their parents do not sign, and so these deaf children are late signers and miss out on many rich early communicative experiences. It is thought that missing out on family discourse about the mind is the major cause of delays in social cognitive development,

as deaf children who are born to deaf parents who are native signers do not show delays in acquiring a theory of mind (e.g., Peterson & Siegal, 1998).

The importance of family dialogue about the mind to pro-social development has been shown most clearly by the experimental work of Dunn (e.g., Dunn, Brown and Beardsall, 1991). Dunn has conducted a number of longitudinal studies of children's social development, and has found highly significant associations between early differences in family talk about feelings (for example, measured in terms of frequency of discussions, causal feeling-state discussions, diversity of themes and disputes) and children's later ability to identify emotions in others (Dunn et al., 1991). The linguistic exchange of information about emotions and their causes, particularly in situations which may be highly emotionally charged for the child, such as a dispute with a sibling, appears to be important developmentally for theory of mind. As noted by Dunn, family conversations about causality offer young children opportunities to enquire, argue and reflect about why people behave in the ways that they do. Intervention studies by Tomasello and his colleagues support the idea that the longitudinal associations demonstrated in Dunn's work are causal in nature (e.g., Lohmann & Tomasello, 2003). Tomasello argues that it is difficult for children to construct an understanding of the representational nature of mental states from visual scenes alone. Rather, rich linguistic communicative experiences are required in order for children to develop adequate social understanding. As noted above, pretend play with peers which entails frequent discussion of mental states also provides these rich linguistic communicative experiences.

Hughes, Dunn and White (1998) studied young children who were “difficult to manage” when aged 4 years, and compared their performance on theory of mind and emotion understanding tasks with 40 age- and gender-matched 4-year-olds from the same urban area of London. They found that the hard-to-manage preschoolers showed delayed understanding of emotion and poorer affective perspective-taking skills, even when family background, language and cognitive ability were controlled. The hard-to-manage preschoolers were also significantly more likely to engage in violent pretend play at the age of 4 years, Violence that involved killing or inflicting pain on another was particularly frequent, and in fact the friends of the hard-to-manage preschoolers often refused to continue with these games (child brandishing sword “Kill! Kill! Kill me!”; friend drops his sword “No”). When the hard-to-manage preschoolers were followed up as 6-year-olds, Hughes and Dunn (2000) found that they showed deficits in moral awareness and in social understanding. Language abilities, theory of mind performance and moral sensitivity were all related in this sample, suggesting developmental continuity in mentalising and language abilities. However, there was also an independent relationship between the violent pretend play measure and individual differences in later moral understanding. The children showing more violent pretend play as 4-year-olds had deficient moral understanding as 6-year-olds.

Hughes et al. (1998) *speculated* that some of these differences could reflect the home lives of the hard-to-manage children, which may have included more hostile interactions. The hard-to-manage preschoolers were more likely than control children to snatch toys, to call their friends names and

to engage in rule-breaking behaviour. Hughes et al. *speculated* that these permissive attitudes towards social transgressions could reflect norms within the children's families. Supportive contexts in which discussions about feelings, thoughts and desires take place are clearly critical to pro-social development. Family interactions are central to the development of social understanding, and in families characterised by violence and aggression and punitive child control, the development of social understanding will be impaired. Poorer emotional regulation and weaker inhibitory control also tend to result from such environments, as shown in studies of children with anti-social behaviour and conduct disorders.

Potential Effects: The internet and video gaming are not likely to provide children with the rich linguistic communicative experiences about emotions, feelings and moral transgressions that are required for effective pro-social and moral development. On the other hand, video gaming in particular can provide repeated experiences of violent, hostile interactions, perhaps with confusing moral messages. It can be *speculated* that children whose families do provide the kinds of communicative contexts critical to pro-social development are unlikely to experience negative developmental effects from playing violent video games, particularly if there is family discussion around the actions and morality of the game characters. It can also be *speculated* that children whose families do not provide the kinds of rich communicative experiences necessary for pro-social development are *more* likely to experience negative developmental effects from playing violent video games. Exposure to violence in itself seems to be a risk factor for violent pretend play, and killing or inflicting pain on another can be frequent

experiences in certain types of video gaming. If there is also heightened emotional engagement in the experienced scenarios (e.g., in virtual reality games), it can be *speculated* that negative developmental effects may be compounded.

Important Caveat: On the other hand, if videos or video games are expressly designed to teach certain aspects of emotional understanding, they can be effective. The only example I am aware of is the *Transporters* videos for improving "emotion reading" in autism spectrum disorders (see Baron Cohen, 2007). These are a series of video stories of toy trains, similar to Thomas the Tank Engine characters, who experience simple events (e.g., losing something precious) and respond with appropriate emotions. Children with autism are fascinated by mechanical objects, and hence the use of these train characters appears to be effective for learning. There is no research showing whether such videos would also be effective for teaching emotional regulation to children who may not be so emotionally engaged by toy trains.

g. <u>Self-Concept</u>

The primary psychological literature for analysing how children develop the notion of self is the attachment literature, as developed by Bowlby (1969). Early parenting and caretaking experiences are thought to lead the child to develop an "inner working model" of the self as either more or less deserving of loving attachment from others. Bowlby classified early attachments as either *secure* (positive and intrinsically rewarding), *insecure-avoidant* (the child was thought to be avoidant of interaction with caretakers, as the parenting experienced was distressing), or *insecure-resistant* (the child was

thought to be very demanding or “clingy” in interactions, in an attempt to alter inconsistent or insensitive parenting). Later research added a category of *disorganised* attachment, defined when the child appears to have no coherent strategy for coping with inconsistency or rejection. The “inner working model” is basically the self-concept, and children with secure attachments are more likely to have a positive self-concept. Children with secure attachments also do better at school, and are at lower risk for later mental health problems.

Fonagy and Target (1997) have argued that if the child’s attachment experiences are coercive, rigid, frightening or severely neglecting, then it is difficult to develop a positive self-concept, and the child will be vulnerable to developing a psychopathology. Fonagy and Target also show that the self-concept is intrinsically related to the child’s capacity for emotional regulation, impulse control and self-monitoring. As noted above (section d), children who lack positive self-concepts find it difficult to experience a continuity of “self” through time, and to create a sense of initiative (or motivation) and distinctness of experience (things that happen to “me”, see Fonagy & Target, 1997). Children who have experienced particularly adverse parenting, perhaps extreme maltreatment or punitive and aggressive child control techniques, are thought to construct a disorganised self-concept, so that there is no central and effective experience of “self”. Such children show very variable behaviour in different contexts. For example, they may show unreflective and impulsive behaviour whenever there is an element of conflict present in a social interaction, but not across all social situations.

The relation of the self-concept to emotional regulation and impulse control is studied via the temperament literature. Although adult psychology

distinguishes *emotion* (this is thought of in terms of conscious pleasure, i.e. “liking”) from *motivation* (this is thought of in terms of cognitive incentives, i.e. “wanting”), emotion and motivation are less clearly separable in young children, who have been argued to operate on the basis of a simpler “desire” psychology (e.g., Wellman, 2002). Children are also less efficient at distinguishing their conscious experience of emotions (their “feelings”) from their emotional “states” (the functional aspects of their emotions, such as crying). The development of temperament is conceptualised in terms of reactivity and self-regulation. Reactivity refers to the excitability, responsivity or arousability of behavioural and physiological systems, such as fear or anger. Self-regulation refers to behavioural and neural processes that function to modulate underlying reactivity, such as those discussed in section (e) above (attentional flexibility, inhibitory control, planning). Rothbart defines the key dimensions of childhood temperament as fear, anger/frustration, positive affect, approach, activity level and attentional persistence (e.g., Rothbart et al., 2000). As discussed in section (e), children become better at monitoring, modulating and regulating more reactive aspects of temperament as language develops, and with the development of working memory and executive function. Emotional regulation undergoes a further major change during puberty, when hormonal changes increase reactivity, and further cortical reorganisation of frontal cortex (a neural area important for inhibitory control) takes place.

Potential Effects: Given that the development of the self-concept depends primarily on parenting experiences and temperament, it seems unlikely that new media would have any profound impact on its development.

On the other hand, no-one (to my knowledge) has developed interactive video games (for example) which focus on caring for the player as a valued individual deserving of loving attachment. Many fairytales are based on stories of orphaned or neglected figures who find love and self-esteem through their adventures (e.g., *Snow White, Cinderella*), and part of their appeal for children appears to lie in these “happy endings”. It is currently unknown whether interactive video gaming along these lines could have positive effects on self-concept for children who have not experienced secure attachments in the home. Certainly, the internet can be a source of support and comfort for adults who have undergone particular traumas, especially relatively unusual ones that are not part of the experience of friends and relations (e.g. rare terminal illness in a child). This appears to be partly because the internet offers contact with a community of others who have undergone very similar experiences and faced very similar challenges. It can be *speculated* that children with a poor self-concept might benefit from such experiencing such supportive communities via the internet. However, it is argued *anecdotally* that children gain support for maintaining detrimental self-concepts via the internet (e.g. via anorexia websites).

3. RESEARCH RECOMMENDATIONS

Given the foregoing analysis, the most pressing research needs with respect to gauging potential harms from new media appear to be:

1. to establish the degree (if any) of unconscious visual perceptual learning of event structure relevant to social cognition in the absence of social interaction (e.g., re: internalisation of amoral structures)
2. to establish the degree to which participation in violent gaming affects violence in pretend play, with respect to emotional regulation etc. (e.g. frequency of inflicting pain on others re: development of empathising, desensitisation to violence, etc.)
3. to establish the kinds of analogies children draw from the internet and video gaming and whether these affect behaviour (e.g., altruistic behaviour, unempathic responses to suffering, “copycat” behaviour)
4. to establish whether core systems for social cognition, such as the mirror neuron system, are engaged by cartoon characters, and if so which features of cartoons are critical (e.g., presence of eyes, type of motion)
5. to establish how good younger children are at quarantining and/or inhibiting information gained via video gaming from information gained through real-world experiences
6. to establish whether active video gaming has positive effects on aspects of self-regulation such as attentional flexibility, and whether these effects transfer beyond the gaming context

7. to establish whether “internet communities” with positive role models could help to develop positive self-concept in children who have had adverse early attachment experiences
8. to establish whether the (anecdotal) reports of active video gaming being “addictive” to the teenage (male) brain has a neural basis

4. EXECUTIVE SUMMARY

Child development is no longer conceptualised as a series of stages, in which children think and reason differently according to normative age bands. Rather, development is understood as an incremental and gradual process, whereby basic aspects of brain function (e.g., statistical learning), social context (e.g., communication from families and peers) and qualities intrinsic to the child (e.g. temperament, basic intellectual ability, language facility) act together to produce learning about how the world is. Such learning can be divided into naïve physics (learning about how objects behave in time and space), naïve biology (learning about animals, plants, inanimates and man-made artefacts), and naïve psychology (learning about mental states, morality and pro-social behaviour). The most significant change from early to later childhood is the development of “metacognition” and “executive function” – the abilities to manipulate your own cognitive relations to information (e.g. monitoring the sources of your knowledge and weighting the quality of the knowledge according to its source) and strategically to self-regulate your emotions, actions and cognitions.

In terms of how new media might affect the development of learning, knowledge construction, language, memory, self-regulation and pro-social development as discussed in this review, some important points are:

- new media, particularly repetitive video gaming, seem likely to provide inputs that will be learned by the brain’s neural statistical learning algorithms. This kind of learning is unconscious, occurs throughout the lifespan, and is difficult to inhibit. It can be *speculated*, for example, that frequent experience of responding to conflict by killing or inflicting pain during video gaming will

lead the brain to store such responses as normative in such scenarios. The learning mechanism is similar to the neural densensitization to images discussed in the Johnson review, but here would apply to casual structures (e.g., how to respond to threat). Learning would be expected to be more effective if action is involved (e.g., if the child is the agent who inflicts pain).

- two powerful learning mechanisms for young children are imitation and learning by analogy. Children imitate what they have experienced in order better to understand it. It can be *speculated* that children will imitate content that they come across on the internet or during video gaming. This could be positive or negative developmentally, depending on the content (e.g., caring for a puppy versus inflicting pain on an enemy). Similarly, analogies could be positive (caring for a plant) or negative (inflicting pain on animals).

- social cognition (understanding mental states, developing morality, developing pro-social behaviour) depends in part on very basic learning about the goal-directed actions of agents, which in part are learned by a specialised neural system for action, imitation and intention-reading called the mirror neuron system. This system may be activated as successfully by cartoon characters (who have eyes and move in biologically-plausible ways) as by real people. Hence it can be *speculated* that this system may learn and represent behaviours and goal-directed actions that are not considered pro-social within the culture, but that are over-represented in certain new media (e.g., violent video gaming over-represents killing, inflicting pain etc.).

- pro-social development also depends on pretend play, particularly imaginary role play, which gives children opportunities to analyse, discuss and understand emotional reactions and mental states. Children’s pretend play

tends to reflect their social experiences. It can be *speculated* that frequent experiences from new media (e.g., YouTube-type sites, video gaming) will be incorporated into pretend play. If these experiences reflect particular themes (e.g. violence), it can be *speculated* that these themes would affect social-cognitive learning. Children who show more violent pretend play as 4-year-olds show less developed moral understanding as 6-year-olds.

- finally, pro-social development depends on rich communicative linguistic experiences about feelings, behaviour and emotions, either during pretend play or in family contexts. Children whose families provide less rich discussion about feelings and behaviours tend to show a poorer understanding of mental states, poorer emotional regulation and weaker inhibitory control of their own behaviour. It can be *speculated* that engagement with new media might reduce opportunities for the family discussions and communicative experiences that are critical for pro-social development.

- explicit memory development is closely linked to linguistic ability, as children with good language skills are better at narrative organisation. Talking about information at the time that it is being learned leads to better retention, and parents with “elaborative” narrative styles have children with better memories. Shared reminiscing provides children with information about how to be a “self” in their culture, and aids the development of the “autobiographical self”. Children who have experienced very disorganised parenting seem to lack a central and effective experience of “self”. It can be *speculated* that such children will be more vulnerable to alternative “selves” on offer on the internet

(e.g., via narrative exchanges in internet chatroom sites) or during role play in video gaming (e.g., when taking roles involving the glorification of violence).

Although the focus of this summary has been on potential harm, basic research in child development also suggests three potentially very positive aspects of new media for child development:

- knowledge construction and the development of expertise requires exposure to relevant knowledge. One positive aspect of the internet is that it enables enormous access to knowledge. It can be *speculated* that this will be of greater value to learning by older children, who have the self-regulatory skills required strategically to orchestrate their own learning.

- the development of self-regulatory skills during the primary years and again during adolescence can be conceptualised in terms of various components such as response inhibition, cognitive flexibility (e.g. holding multiple perspectives in mind) and planning. It can be *speculated* that new media, particularly purpose-designed video gaming, could lead to the development of such skills (e.g., games requiring complex planning, games requiring salient responses to be inhibited for strategic reasons). It is completely unknown whether such practice would generalise beyond the gaming context, however (e.g., to planning exam revision).

- in terms of the development of the self-concept, the main review outlined how experiencing coercive, hostile or severely neglecting parenting damages the self-concept and also impedes the development of emotional regulation and impulse control. It can be *speculated* that just as dysfunctional self-concepts can be endorsed by finding groups of internet users with similar preoccupations (e.g., anorexia websites), it might be possible to foster more

positive self-concepts in children (e.g., by creating communities of users who faced early adversity but were able to overcome this and develop a positive self-concept).

In conclusion, although a lot is known about the mechanisms of child development, there is almost no empirical research relating to the question of potentially harmful effects of the internet and video games on child development. It seems plausible that very basic forms of learning, such as neural perceptual learning, would be influenced by new media just as they are influenced by any experience. However, of central importance is that we are social animals with social brains. Learning is most effective when it is supported by social and cultural contexts, and when it is transmitted by face-to-face communication. Gaming and the internet are not social agents who can communicate using social cues. Hence what is learned from them may well be limited and non-transferable to the real world. On the other hand, they do provide a “cultural context”. Internet sites such as YouTube can provide shared experiences between a peer group that may transmit quite different messages about morality or selfhood to mainstream “cultural experiences”. There is no reason to think that these shared “social” contexts would not also mediate learning, at any age.

Of course, humans can use language (“inner speech”) and cognitive self-regulation to inhibit the impact of learning that is not useful, and to quarantine what is imaginary from what is real. As younger children tend to have poorer language skills and poorer quarantining abilities, learning from new media could be *speculated* to have stronger effects on younger children. Alternatively, as older children are more responsive to the peer group and

have the skills required to seek out certain kinds of input from new media, it could be *speculated* that new media that is endorsed by the peer group will have stronger effects during the adolescent years. Hormonal and other brain-related changes during adolescence make this a time when all children question their identities and their “autobiographical selves”. New media can offer learning experiences relevant to resolving some of these questions, just like any other form of experience. *A priori*, new media do not seem likely to be less influential as a source of information, however, there is no relevant research that I am aware of.

Bibliography

Arterberry, M. E., & Bornstein, M. H. (2001). Three-month-old infants' categorization of animals and vehicles based on static and dynamic attributes. Journal of Experimental Child Psychology, 80, 333-346.

Barsalou, L.W., Simmons, W.K., Barbey, A.K., & Wilson, C.D. (2003). Grounding conceptual knowledge in modality-specific systems. Trends in Cognitive Sciences, 7, 84-91.

Baron-Cohen, S. (2007) Transported into a world of emotion. The Psychologist, 20, 76-77.

Bartlett, F.C. (1932). Remembering. Cambridge: Cambridge University Press.

Blair, R.J.R. (2008). Fine cuts of empathy and the amygdala: Dissociable deficits in psychopathy and autism. Quarterly Journal of Experimental Psychology, 61, 157-70.

Blaisdell, A.P., Sawa, K., Leising, K.J. & Waldmann, M.R. (2006). Causal reasoning in rats. Science, 311, 1020-1022.

Bowlby, J. (1969) Attachment , Vol. 1 of Attachment and loss. London: Hogarth Press. New York: Basic Books.

Brown, A. L. (1989). Analogical learning and transfer: What develops? In S. Vosniadou & A. Ortony (Eds.) Similarity and analogical reasoning, (pp. 369-412). Cambridge, UK: Cambridge University Press.

Brown, A.L., & Scott, M.S. (1971). Recognition memory for pictures in preschool children. Journal of Experimental Child Psychology, 11, 401-412.

Bullock, M., Gelman, R., & Baillargeon, R. (1982). The development of causal reasoning. In W.J. Friedman (Ed.), The Developmental Psychology of Time, pp. 209-254. New York: Academic Press.

Cameron-Faulkner, T., Lieven, E., & Tomasello, M. (2003). A construction based analysis of child directed speech. Cognitive Science, 27, 843–873.

Carlson, S.M. & Moses, L.J. (2001). Individual differences in inhibitory control and children's theory of mind. Child Development, 72, 1032-1053.

Carpenter, M., Call, J. & Tomasello, M. (2005). Twelve- and 18-month-olds copy actions in terms of goals. Developmental Science, 8, F13-F20.

Chomsky, N. (1957) Syntactic Structures. Berlin: Mouton de Gruyter.

Chouinard, M., & Clark, E. (2003). Adult reformulations of child errors as negative evidence. Journal of Child Language, 30, 637-669.

Dapretto, M., Davies, M.S., Pfeifer, J.H., Scott, A.A., Sigman, M., Bookheimer, S.Y., & Iacoboni, M. (2006). Understanding emotions in others: Mirror neuron dysfunction in children with autism spectrum disorders. Nature Neuroscience, 9, 28-30.

Dehaene-Lambertz G, Hertz-Pannier, L., Dubois, J., Meriaux, S., Roche, A., Sigman, M., & Dehaene, S. (2006): Functional organisation of perisylvian activation during presentation of sentences in preverbal infants. Proceedings of the National Academy of Sciences, 103, 38, 14240-14245.

Dollaghan, C.A. (1994).Children's phonological neighbourhoods: Half empty or half full? Journal of Child Language, 21, 257–271.

Dunn, J., Brown, J., & Beardsall, L. (1991). Family talk about feeling states and children's later understanding of others' emotions. Developmental Psychology, 27, 448-455

Dunn, J., & Cutting, A.L. (1999). Understanding others, and individual differences in friendship interactions in young children. Social Development, 8, 201-219.

Farroni, T., Csibra, G., Simion, F., & Johnson, M.H. (2002). Eye contact detection in humans from birth. Proceedings of the National Academy of Sciences, 99, 9602-9605.

Fenson, L., Dale, P.S., Reznick, J.S., Bates, E., Thal, D., & Pethick, S. (1994). Variability in early communicative development. Monographs of the Society for Research in Child Development, 59 (5, Serial No. 242).

Fivush, R., & Hammond, N.R. (1990). Autobiographical memory across the preschool years: Toward reconceptualising childhood amnesia. In R. Fivush & J. Hudson (Eds.), Knowing and Remembering in Young Children. New York: Cambridge University Press.

Fonagy, P., & Target, M. (1997). Attachment and reflective function: Their role in self-organization. Development & Psychopathology, 9, 679-700.

Gergely, G., Bekkering, H., & Király, I. (2002). Rational imitation in preverbal infants. Nature, 415, 755.

Gopnik, A., Sobel, D., Schultz, L., & Glymour, C. (2001). Causal learning mechanisms in very young children: Two, three, and four-year-olds infer causal relations from patterns of variation and covariation. Developmental Psychology, 37, 5, 620–629.

Goswami, U. (1991). Analogical Reasoning: What develops? A review of research and theory. Child Development, 62, 1-22.

Goswami, U. (2001). Analogical reasoning in children. In Gentner, D., Holyoak, K. J., and Kokinov, B. N. (Eds.), The analogical mind: Perspectives from cognitive science (pp. 437-470). Cambridge, MA: MIT Press.

Goswami, U. (2008). Cognitive Development: The Learning Brain. Psychology Press.

Goswami, U. & Brown, A. (1989) Melting chocolate and melting snowmen: Analogical reasoning and causal relations. Cognition, 35, 69-95.

Greco, C., Hayne, H., & Rovee-Collier, C. (1990). Roles of function, reminding and variability in categorization by 3-month-old infants. Journal of Experimental Psychology: Learning, Memory & Cognition, 16, 617-633.

Harris, P. L., Brown, E., Marriott, C., Whittall, S., & Harmer, S. (1991). Monsters, ghosts, and witches: Testing the limits of the fantasy-reality distinction in young children. British Journal of Developmental Psychology, 9, 105-123.

Hart, B.H. & Risley, T.R. (1995). Meaningful differences in the everyday experience of young American children. Baltimore, MD: Paul H. Brookes.

Hauk, O, Johnsrude, I.S., Pulvermuller, F. (2004) Somatotopic representation of action words in human motor and premotor cortex. Neuron, 41, 301-307.

Hudson, J.A. (1990). The emergence of autobiographical memory in mother-child conversation. In R. Fivush & J. Hudson (Eds.), Knowing and Remembering in Young Children. New York: Cambridge University Press.

Hughes, C. (1998). Executive function in preschoolers: Links with theory of mind and verbal ability. British Journal of Developmental Psychology, 16, 233–253.

Hughes, C., & Dunn, J. (2000). Hedonism or empathy? Hard-to-manage children's moral awareness, and links with cognitive and maternal characteristics. British Journal of Developmental Psychology, 18, 227–245.

Hughes, C., Dunn, J., & White, A. (1998). Trick or treat? Uneven understanding of mind and emotion and executive dysfunction in hard-to-manage preschoolers. Journal of Child Psychology & Psychiatry, 39, 981-994.

Inagaki, K., & Hatano, G. (1987). Young children's spontaneous personification as analogy. Child Development, 58, 1013-1020.

Inhelder, B., & Piaget, J. (1958). The growth of logical thinking from childhood to adolescence. New York: Basic Books.

Kaiser, M.K., Profitt, D.R. & McCloskey, M. (1985). The development of beliefs about falling objects. Perception & Psychophysics, 38, 533-539.

Kaufman, J., Csibra, G., & Johnson M.H. (2003). Representing occluded objects in the human infant brain. Proceedings of the Royal Society of London B (Suppl.), 270, S140-S143.

Kochanska, G., Murray, K., Jacques, T.Y., Koenig, A.L., & Vandegeest, K. (1996). Inhibitory control in young children and its role in emerging internalization. Child Development, 67, 490-507.

Kuhl, P.K. (2004). Early language acquisition: Cracking the speech code. Nature Reviews Neuroscience, 5, 831-843

Kuhl, P. K., Tsao. F.-M., & Liu, H.-M. (2003). Foreign-language experience in infancy: Effects of short-term exposure and social interaction on phonetic learning. Proceedings of the National Academy of Sciences, 100, 9096-9101.

Leslie, A.M. (1987). Pretense and representation: The origins of "theory of mind". Psychological Review, 94, 412–426.

Lillard, A. S. (2002). Pretend play and cognitive development. In U. Goswami (Ed.), Handbook of cognitive development (pp. 188-205). London, Blackwell.

Lohmann, H., & Tomasello, M. (2003). The role of language in the development of false belief understanding: A training study. Child Development, 74, 1130-1144.

Meltzoff, A.N. (1988). Infant imitation after a 1-week delay: Long-term memory for novel acts and multiple stimuli. Developmental Psychology, 24, 470-476.

Meltzoff, A.N. (1995). Understanding the intentions of others: Re-enactment of intended acts by 18-month-old children. Developmental Psychology, 31, 838-850.

Meltzoff, A. (2002). Imitation as a mechanism for social cognition: Origins of empathy, theory of mind and the representation of action. In U. Goswami (Ed.), Blackwell Handbook of Childhood Cognitive Development (pp. 6-25). Oxford, UK: Blackwell.

Meltzoff, A.N. (2007). 'Like me': a foundation for social cognition. Developmental Science, 10, 1, 126-134.

Meltzoff, A.N., & Moore, M.K., (1983). Newborn infants imitate adult facial gestures. Child Development, 54, 702-709.

Michotte, A. (1963). The Perception of Causality. Andover: Methuen.

Nelson, K. (1986). Event Knowledge: Structure and Function in Development, Hillsdale, NJ: Lawrence Erlbaum Associates.

Nelson, K., & Fivush, R. (2004). The emergence of autobiographical memory: A social cultural developmental theory. Psychological Review, 111, 486-511.

Pauen, S. (1996). Children's reasoning about the interaction of forces. Child Development, 67, 2728-2742.

Peterson, C., & Siegal, M. (1995). Deafness, conversation and Theory of Mind. Journal of child Pschology & Psychiatry, 36(3), 459-474.

Petitto, L. A., & Dunbar, K. N. (in press). New findings from educational neuroscience on bilingual brains, scientific brains, and the educated mind. In K. Fischer & T. Katzir (Eds.), *Building Usable Knoweldge in Mind, Brain and Education*. Cambridge: Cambridge University Press.

Piaget, J. (1954). The construction of reality in the child. New York: Basic Books.

Reese, E., Haden, C.A., & Fivush, R. (1993). Mother-child conversations about the past: Relationships of style and memory over time. Cognitive Development, 8, 403-430.

Riecke, L., van Opstal, A.J., Goebel, R., & Formisano, E. (2007). Hearing illusory sounds in noise: Sensory-Perceptual Transformations in Primary Auditory Cortex. Journal of Neuroscience, 27, 12684 - 12689.

Rizzolatti, G., & Craighero, L. (2004). The mirror neuron system. Annual Review of Neuroscience, 27, 169-192.

Rothbart, M.K., Ahadi, S.A., & Evans, D.E. (2000). Temperament and personality: Origins and outcomes. Journal of Personality and Social Psychology, 78, 122-135.

Scheier, C., Lewkowicz, D.J., & Shimojo, S. (2003). Sound induces perceptual reorganization of an ambiguous motion display in human infants. Developmental Sciences, 6, 233-244.

Scholl, B.J., & Tremoulet, P.D. (2000). Perceptual causality and animacy. Trends in Cognitive Sciences, 4, 299-309.

Schultz, D., Izard, C.E., & Bear, G. (2004). Children's emotion processing: Relations to emotionality and aggression. Development & Psychopathology, 16, 371-387.

Sekuler, R., Sekuler, A.B., & Lau, R. (1997) Sound alters visual motion perception. Nature, 385, 308.

Shultz, T.R. (1982). Rules of causal attribution. Monographs of the Society for Research in Child Development, 47, 194.

Sommerville, J.A., Woodward, A.L., & Needham, A. (2005). Action experience alters 3-month-old infants' perception of others' actions. Cognition, 96, B1-B11.

Spelke, E.S. (1991). Physical knowledge in infancy: Reflections on Piaget's theory. In S. Carey & R. Gelman (Eds.). The Epigenesis of Mind: Essays on Biology and Cognition, pp. 133-169. Hillsdale, NJ: Lawrence Erlbaum.

Tai, Y.F., Scherfler, C., Brooks, D.J., Sawamoto, N., & Castiello, U. (2004). The human premotor cortex is 'mirror' only for biological actions. Current Biology, 14, 117-120.

Van Abbema, D.L., & Bauer, P.J. (2005). Autobiographical memory in middle childhood: Recollections of the recent and distant past. Memory, 13, 829-845.

Vygotsky, L. (1978). Mind in Society. Cambridge: Harvard University Press.

Vygotsky, L. (1986). Thought and language. Cambridge, MA: MIT Press.

Wellman, H.M. (2002) Understanding the psychological world: Developing a theory of mind. In U. Goswami (Ed.) Handbook of Childhood Cognitive Development (pp. 167-187). Oxford: Blackwell.

Wellman, H. M., & Gelman, S. A. (1998). Knowledge acquisition in foundational domains. In W. Damon, D. Kuhn & R. Siegler (Eds.), Handbook of Child Psychology, 5th Ed., Volume 2, Cognition, Perception and Language, pp. 523-573. New York: Wiley.

Winston, P.H. (1980). Learning and reasoning by analogy. In Communications of the ACM, 23 (12), December 1980.