Specific Modes of Physical Activity and Cognitive Development in Children

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Introduction

Recent times have seen a significant decline in the level of children's Physical Activity (PA)[1]. This has led to a dramatic increase and earlier onset of preventable chronic health disorders also leading to negative psychological, behavioural and cognitive outcomes[2,3]. Obesity maybe a relational factor in the inactivity related ill-health epidemic, whilst recent research suggests physical inactivity to be primarily causal[3]. The trend towards early onset of illness related disorders associated with physical inactivity has been amplified by a move in advanced economies towards reduced PE and increased academic tasks in primary schools, based on the false hope of enhanced academic success[4]. The reverse is most likely true leading to a double disorder of declining PA and reduced optimisation in academic performance[4]. Regular doses of PA are protective against the onset of these disorders and can reverse the effects of physical inactivity related ill health if enhanced levels of PA is implemented[3,5].

The positive effect of PA in pre-adolescents cognitive and academic development is now well documented and serves to support the re-implementation of PA in primary schools[6,7,8]. The traditional PE approach relating PA to childhood cognitive development and academic performance has centred on non-specific intensity based physical activities reliant on high metabolic cost and load forces (known as quantitative styles of PA). Examples of intensity based PA includes running laps and beep tests[6]. The influence of quantitative programs on cognitive performance and organisation is proposed to centre on increased brain vascularity, non-specific cortical and sub-cortical neurogenesis and increased arousal levels of participants[6,7,8].

Qualitative Approach

A growing body of research supports the role of specifically designed physical activities related to the production of precise qualities of a movement sequence and is termed the “qualitative approach” (QA)[9,10] (see box 1 available as appendix at www.aima.net.au). QA programs take into account unique human developmental characteristics embedded in physical activities co-joined with cognitive development. QA in human movement is proposed to have a significant influence on cognitive development because of factors related to the extended period of human neuro-development and the immature state of the new born brain[11]. Physical experience moulds neural connectivity during this early and extended developmental stage promoting a refinement and expansion of connections and pruning inactive neurones and their synapses[12]. Extended neuro-development and the rapidly expanding experience modulated paediatric brain promotes neuro-plastic changes in critical beds of human cognitive neurones, having future roles in executive functions and spatial organisation[9,10,11,12,13,14]. In Australia organised school based programs such as the “Bluearth Approach” and teacher education based training illustrated by the “Essential Moves” and “Move to Learn” programs are at the cutting edge of qualitative styles of physical activities.[15,16,17]

Neuro-development, Individual Domain Specific Expertise and “By Chance” Phenomena in Human Cognition

Children undergo a prolonged neural and physical maturation supporting the process of slow skills acquisition arising from low to medium based intensities. The development and refinement of locomotion, communication style, dexterity, eye movements, behavioural profiles and academic capabilities unique to modern Homo sapiens requires a long period of organisation in the cognitive and executive control elements of the cerebral cortex as well as sub cortical and sensory absorption elements. Human cognitive functions also require advanced neural forward models (also requiring prolonged maturation) believed to exist within specific cortical and sub-cortical networks. Contributing factors in cognitive development from PA include the role of primitive reflexes and stereotypical postures, the style of movement, the accuracy of performance, the intention of the actor, concentration, attention, planning, attitude, beliefs and the consequences of the action. Timing, fluency, increased complexity, sequencing, Postural Stability (PS), breathing, accurate intensity and endurance as well as other factors play crucial roles in QA PA interventions[9,10]. Of paramount importance is the accuracy in which the child performs the movement task, the formulated movement intention matching age related cognitive development and the relationship of the participant to the task in connection with intrinsic and extrinsic motivations [9,10]. It is then equally important the programs (either in direct contact with the children or via teacher/coach training by appropriate organisations) are conducted by well trained, skilled movement professionals who support many roles including coach, mentor and choreographer.

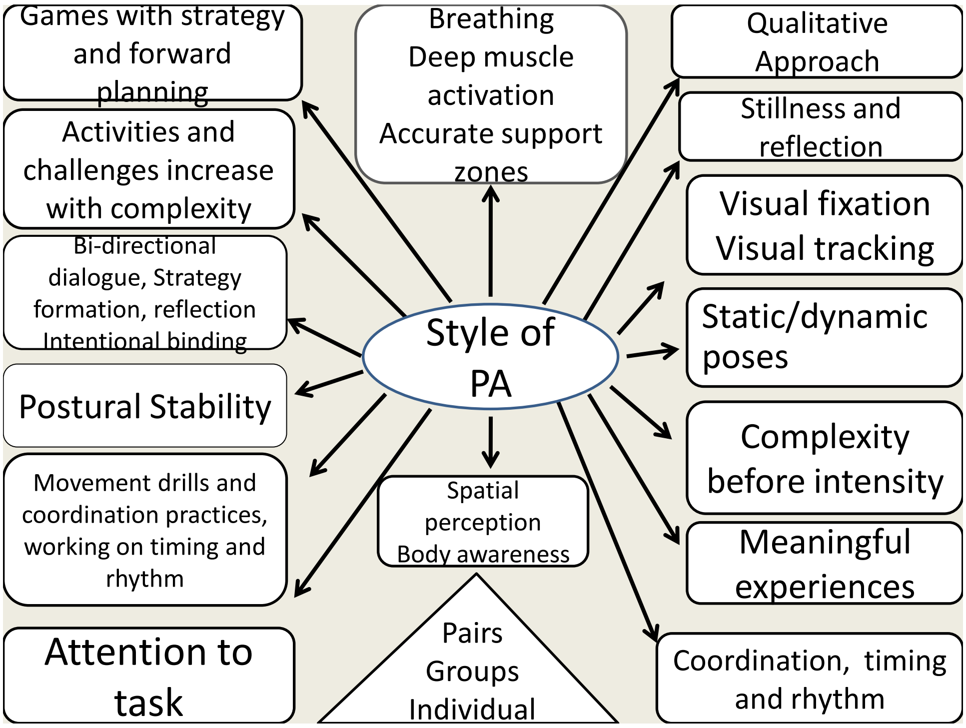

Figure 1. Activities included in QA to PA

The QA is proposed to provide greater specific modulation on the CNS due to unique phylogenic and ontogenic characteristics of modern humans[9,10]. A crucial factor in the emergence of human cognition is related to the unique human trait of Individual Domain Specific Expertise (IDSE) arising from and bound to the extended infant neuro-development and emergent in modern human social groups (and not in sub human hominids)[18,19,20]. In the tribal group many experts often emerged with specialised expertise in specific fields of tribal life (usually associated with PA endeavours). This process has evolved and adapted for changing circumstances over time and is still a foundational principal of modern human existence.

Ancient human tribal groups exhibited generalised competencies for ADL's with numerous specific individuals expressing explicit capabilities beyond normal competency and into the realm of expertise (IDSE) and is proposed by Skoyles

1999[19,20] and Sternberg 1999[21] to be the underlying evolutionary pressure in the emergence of IQ. Cognitive processes supporting academic performance and IQ may have their origins in human evolutionary trait exposed in IDSE.

“By chance” natural abilities in children were noted and mentored so that future experts would emerge providing necessary expert skills for tribal survival[19,20]. “By chance” innate proclivity in human infants is proposed to be bestowed as an evolutionary characteristic for the unique human ability to form IDSE[19,20,21,]. However, the “by chance” individual characteristic can also “fall to the other side” so that “by chance” the infant is provided with reduced competencies and lower advantages – just as Darwin predicts. The Darwinian “by chance” phenomenon is dynamically expressed in the unique heterogeneous nature of all humans[22,23] and in a small but important part explains the heterogeneous nature of learning and behavioural problems in infants and adolescents when natural proclivities by chance “fall to the other side”.

IDSE is fostered and moulded by the post birth highly plastic and uniquely expanded brain[13,19]. The plasticity of the human brain is most active from birth to puberty and relies on moderate to low intensity PA associated with QA to mould and modulate neural functional densities and connectivity in the expanding brain[11]. This process then serves as the organisational template for more complex processing during later stages of development and adapted to adult cognitive tasks. The highly plastic human brain responds to enriched environments with improved cognitive function and supports the role of movement and experience acquisition with IDSE model of human cognition[11]. Physical activities with meaning and consequence fuel the mechanisms for cognitive growth. Thinking, planning, acting and contemplating are interwoven phenomena separated only by temporal circumstance and bound by intention and the “deed”.

The Unlink and Unlock Phenomena and Human Cognition

Humans are unique in the animal kingdom, in part because the fundamentals of intentionally directed movement and thought construction share common beds of neurones also responsible for the emergence of IDSE traits[13,14]. Human styles of movement and the human styles of thought share complex neural connections allowing a common style of orchestration of thought and movement - known as the "Unlock and Unlink" (UU) strategy[13,14,24]. Unlike all other animals, whose primitive thought processes and stereotypical actions are held separate and encapsulated within neural control networks, healthy adult humans, compared to all other animals, have the unique capacity to UU:

1. Sequential articular motion segments[13,,24,25,26]
2. The eyes from head movements to form specific "quiet eye" and visual fixation strategies[27],
3. The jaw and epiglottis to produce controlled expiration with meaningful sound producing language[28,29], and
4. Mechanisms to manipulate information to produce meaningful thoughts predictions, plans and strategies.

The UU strategy for all parcels of movement and thought construction arises from common beds of neurones, with the most significant located in the dorso-lateral Pre-Frontal Cortex (PFC)[30], Posterior Parietal Cortex (PPC) uniquely expanded in the human brain linking the common functions of human cognition and intentional movements and provide the advanced forward predictive model simulations acting as the foundation of cognition[30,31,32,33]. All other animals devoid of such expanded and sophisticated neural complexities also lack the ability to conduct any UU strategies.

Human Infants also use a Lock and Link (LL) strategy essential for normal development known as “lock down”[24]. Both infant and animal LL strategies are based primarily on stereotypical and reflexive movement behaviours arising primarily from spinal cord, brain stem and midbrain structures, modulated by motor cortical zones. Animal and infant movement behaviours appear sophisticated and fluent but lack flexibility in application and adaptability when circumstances change and novel, complex environmental challenges emerge. Infants’ progress through this LL stage and it is through the activity of the above mentioned (uniquely expanded and connected in humans) neural structures and the possible inhibition by the PFC and PPC of motor and pre-motor cortical sites responsible for transitional (lock down) postural control strategies.

The Three Neurological Interdependent Levels Essential Human Cognitive Development

Three processes actively engaged in the infant neurology to support the physical experience modulation of brain function and cognitive development:

1. “**Bottom Up” (BU) Sensory absorption and disambiguation**.

The physical world is made up of energy fields available to animals through specific energy frequency responsive sensory receptors. The available specific energenic frequencies are absorbed by specific sensory receptor sites, then through the process of active pursuit of movement experience and accurate movement portrayal – the sensory signals are disentangled, topographical organised and amalgamated into an accurate neurological reflection of the specific stimuli that will be further processed up the hierarchical neurological chain[34]. Specific movements may influence the accurate integration of sensory inputs through exact performance of complex movements contributing mostly to the BU effect [35,36]. The BU process is the basis for many qualitative based movement programs illustrated by the "Bluearth Approach" (see www.bluearth.org.au) and sensory integration training[15,16,17,35,36]. The BU effect on cognitive development may be more influential in children with learning difficulties compared to children with normal learning competencies[16,17,35,36]. Therapists using qualitative approaches during sensory-motor integration in the treatment of children with learning difficulties often theorise that the learning difficulties arise from poorly organised or dysfunctional lower brain zones[16,17,35,36]. These zones located in the brain stem and midbrain act to influence cognitive development in a BU fashion and can have a profound cascading negative influence when primitive reflexes are retained rather than inhibited[35,36,37,38]. Some researchers and therapists alike also propose retained primitive reflexes, commonly seen in pre-pubescent children who have suffered birth traumas, plagiocephaly or infant stress syndromes are often significantly associated with vestibular based dysfunctions[16,17,35,36,38]. In diagram 1 and 2 we see a child performing a postural manoeuvre. The accurate and expertly directed performance is proposed to inhibit still active portions of the Symmetrical Tonic Neck Reflex (STNR). It is proposed active engagement in this series of movements in non-directed freely performing children will often facilitate elements of the primitive form of PS, but through expert direction and accurate performance of a preferred movement strategy, conscious inhibition of the still active portions of the STNR will promote optimal movement performance, reduced ambiguity in body perception and formation of more accurate sensory maps, then facilitate greater efficiency in CNS for cognition functions.

Diagram 1 and 2 Illustrate the Set up phase of QA exercise designed to inhibit STNR and the end phase of the exercise. Photo's courtesy of Essential Moves.

2. **Intermediate Processes: Organisation and Integration of Sensory Inputs**

The Cerebellum (CB) and Basal Ganglia (BG) modulate cortical inputs by receiving a neural stimulus, influencing then returning to the same neurone (known as re-entrant stimulus) an altered and adapted afferent signal[31]. The function of both sites has historically ascribed to the control and facilitation of human movements; however recent research supports the role of the CB and BG in higher cognitive functions. Koziol and Budding 2010 suggest the function of CB and BG in movement control persist and are utilized as similar strategic controls for emotional and cognitive regulation[31,32,33].

3. **Top down (TD) higher cognitive functions of dorso-lateral pre frontal cortex and posterior parietal cortex**

The PFC and PPC unify input from the BU process and re-structure the data into non-temporal information linking past experience, relevant current stimulus and task intentions into a functional and modular format for the solution to present tasks. The PFC and PPC are significantly linked to cognitive function and academic performance[39,40,41,42]. The stimuli are represented in terms of their relevance to current behaviour rather than in terms of simple sensory properties[29,33]. A range of different cognitive demands all appear to activate a similar network of frontal and parietal areas[30,33,41] including attentional controls, forward planning, short term memory, PS, spatial awareness and numeracy[30,33,34,40,41,42,43]. The PFC and PPC are connected to processing mechanisms for tasks requiring complexity or uncertainty[30].

The association cortex's can be influenced through PA via the modulatory effects of:

1. Movement Complexity,
2. Intentions,
3. Purposeful visual fixation and scanning strategies and
4. Constant accurate awareness of the task, the action space and the body embedded in the field of action.

The dorso-lateral PFC can be modulated by specific and accurate postural stability tasks with temporal sequencing, evolving complexities and attentional focus with functional task demands. The posterior parietal cortex can be facilitated by aspects of self and spatial awareness.

Pre-frontal Cortex and posterior Parietal Cortex in Pre-pubescent Children

In children the PFC and PPC utilize a significantly altered neurological firing pattern compared to adults with much larger areas of the bilateral PFC activity and a larger activation of the right PPC (areas more related to physical experiences) for cognitive tasks such as numeracy [30,33,39]. Boys and girls have differently structured parietal and frontal cortex's, which is amplified by sex hormone influences and life experiences[12,44].

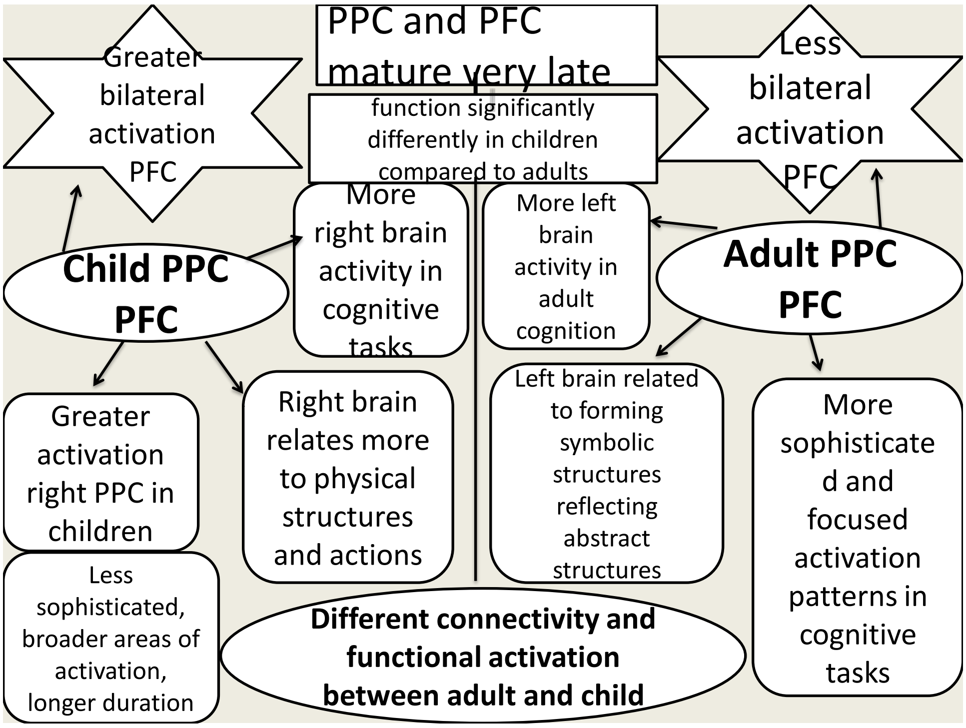

Figure 2. Differences between children and adults in cognitive functions

Boys and girls process sensory input differently, have different areas of higher cortical densities and connectivity and solve academic tasks in different ways[30,33,39]. This should be taken into account when implementing movement for learning programs. It is important to note the PFC is active during tasks that are complex, novel or have multiple tasks. As the pre-pubescent child progressively experiences activities often for the first time and new tasks are also relatively complex, it stands to reason the PFC and PPC are significantly active during most PA tasks and is the process most effected by qualitative movement procedures.

Conclusion

It is clear and apparent that reduced physical activity levels in pre-pubescent children is having health and wellness consequences. Aligned to this phenomenon is a probable reduction in optimal cognitive and academic performance due to a reduction in age appropriate meaningful physical experiences. Recent evidence supports the use of physical activities for enhanced cognitive and academic performance. In particular a growing body of evidence supports the used of qualitative measures for enhanced, cognitive, behavioural and academic performance. QA assume many different forms and practices but are unified by the nature, intention and consequences of movement performances

In children PFC and PPC neuronal beds activate in similar patterns for physical experiences and academic tasks (particularly numeracy), with activation patterns notably different to those exhibited in healthy adults. It is the authors' contention that intentionally guided specific movement tasks as part of a group activity, in pairs or individual lessons may enhance cognitive development, executive control and academic performance, over time. TD cortical brain structures may be particularly influenced by qualitative PA procedures and the effect supported and intensified by a combination of BU, TD and "intermediate" mechanisms.

Whilst Australian practitioners have a long pioneering history in the development and provision of qualitative physical activity programs[15,16,17,45,46,47,48] greater research is needed in the use of qualitative measures for cognitive related outcomes in pre-pubescent children. Present sets of data are promising possible significant group and individual effects in qualitative PA programs for optimal cognitive development (See box 1). There is a need to understand more fully the complexities and application of qualitative based PA programs. It is also essential QA to PA programs be conducted by highly trained and skilled individuals in order to receive the full benefit of any program[15,16,17,45,46,47,48]. QA should be considered as essential ingredients in any school and learning rehabilitation curriculum. Most pre-pubescent children will benefit from qualitative based PE, whilst specific groups of children with learning, movement and/or behavioural problems will most likely receive the greatest benefit. Qualitative elements of PA are proposed to enhance and accelerate specific neural modulations and connectivity essential for optimal human cognition. This review aims to provide foundations for health professionals and educationalists using physical movements for optimal physical, emotional and cognitive development in children.

Conflict of Interest

Wally Johnston has a role as an advisor to the "Essential Moves" program. No other conflict of interest is noted.

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Appendix

box 1. Summary of selected papers exploring Qualitative PA and cognition follow links at www.aima.net.au