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The relationship between lead exposure, motor function and behaviour in Inuit preschool children

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Abstract

The main focus of this study was to determine the role of behaviour in the relationship between postnatal lead exposure and motor function. The sample consisted of 110 preschoolers, of age 5, from Nunavik. Lead concentration was measured at birth and at testing time. Average lead levels were of 4.9 μg/dL (0.24 μmol/L) and 5.3 μg/dL (0.26 μmol/L) for cord and child blood, respectively. Children's balance and fine motor capacities were tested. A modified version of the IBR was used to assess behaviour. Postnatal blood lead concentrations correlated positively with both impulsivity and activity. Neither pre- nor postnatal blood lead concentration correlated with attention level. The children's scores on impulsivity (I) and activity (A) were summed to create the independent variable IA, which was tested as a potential mediator between lead exposure and two dependent variables: the coefficient of covariation in alternating hand movements and transversal sway in tandem position. Mediation was significant only for the latter variable. IA and attention were then tested as potential moderators in the relation between postnatal lead exposure and motor function. No significant interaction between independent variables could be observed. These results do not support the hypothesis that, at low levels of postnatal exposure, lead acts indirectly on motor function via behaviour. However, IA does act as a mediator in the relationship between postnatal blood lead concentration and transversal sway in tandem position.

Keywords: Lead; Behaviour; Motor function; Prenatal exposure; Postnatal exposure; Mechanisms of action; Mediation; Moderation

1. Introduction

Lead exposure has been a major public health issue in the past decades. Although blood lead concentrations have reduced dramatically in the general population [2,5], recent studies have suggested that prenatal and early postnatal exposure to very low doses of lead can adversely affect certain aspects of a child's development, including fine motor function, memory, learning and behaviour [7,17,19,24,36]. While the vulnerability of the developing brain to lead has been well documented, the neurotoxin's mechanism of action remains unclear. To date, epidemiological studies have attempted to define populations at greatest risk as well as the array of deficits found in exposed individuals. However, researchers have still not been able to decode 'lead's signature' [8,61]. Many scientists believe that the divergent observations concerning lead's impact may be partly due to the complex nature of lead's mechanism of action. At lower levels of exposure, a number of variables including dose, time of exposure, individual variability and other moderating variables seem to interact in a complex fashion. This makes it difficult to define the direct effects of lead, the potential mediators and the threshold at which such effects can be seen [8,50]. One possible explanation for this lack of understanding may be that most epidemiological research in this field has focused on specific domains of development, testing only a certain number of tasks per cohort without studying patterns of coexisting deficits in children exposed to background levels of lead [57]. As prominent researchers in the field have pointed out [6,54], lead's impact on behaviour may indirectly lead to a variety of developmental problems. Rice noted that many of the cognitive deficits observed in exposed children may be better explained as an outcome of behavioural

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deficits. Therefore, by trying to unravel the relationship between the four coexisting effects of lead exposure, it may be possible to better understand the neurotoxic mechanism of this metal [54].

1.1. Lead's mechanism of action

It is still unclear how lead impacts on different cognitive, behavioural and motor capacities. Lead has neurochemical effects at various levels including molecular, cellular and intracellular [60]. At lower doses, it seems as though lead mainly alters calcium homeostasis, causing disruption in neurotransmitter systems [1,2,39,43]. Areas such as the prefrontal cortex, hippocampus, hypothalamus, nucleus accumbens, the brain stem and the cerebellum are commonly cited as being vulnerable to lead's neurochemical effects [30,35,38]. The neurotransmitters most affected include noradrenaline, dopamine, serotonin and acetylcholine, which are essential in the regulation of our emotional, cognitive and locomotive responses [26,44,60]. Neurotransmitters appear early on in brain development [70] and serve a crucial function in the development of synapses and dendrites, which in turn create cortical circuits for the transmission of signals from one area of the brain to another [11,57]. Synaptogenesis is a process that initiates in the first weeks of life, proliferates in the first 3 years and continues until late adolescence [26]. During the initial stages of life, disruption in this system could cause irreversible damage to the circuits preventing signals from occurring normally between various brain regions, which can later manifest itself in global cognitive, behavioural or motor dysfunctions. However, considering the progressive nature of neural development, researchers have argued that different critical periods of vulnerability exist depending on the region of the brain. Neurological disruption will also vary in its degree depending on the time of exposure to the toxin. This concept of a critical period of vulnerability is well known in the area of toxicology and has been used to understand the heterogeneity in deficits found in exposed individuals [5,57].

1.2. Effects of lead on behaviour

A multitude of studies have observed behavioural deficits in children exposed to lead. Hyperactivity, decreased attention span, impulsivity, distractibility, inability to inhibit inappropriate responding and non-persistence often correlate with blood lead levels in humans and non-human animals [15,18,46,55,59]. Most studies in this field have looked at the relationship using exposure versus non-exposure as an independent variable where pre-determined concentration levels are considered as being a sign of exposure. For example, Mendelsohn et al. [45] found significant differences in the Bayley's Behaviour Rating Scale scores of 1- to 3-year-old children whose blood lead levels were between 10 μg/L and 24.9 μg/L (0.48 μmol/L and 1.20 μmol/L) compared to children with lower levels.

However, recent research demonstrates that the relationship between lead exposure and children's behaviour may be linear with no detectable threshold of effect. In a group of 6–9 year olds, the Rutter scale was used to assess behaviour. Analyses revealed a significant association between aggressive/antisocial behaviour and hyperactivity, and blood lead levels where no evidence of a threshold effect was detected [65]. Although the average blood lead level in this groups of children was 10.4 μg/dL, Chiodo et al. [19] found similar results in a group of 7 year olds where average blood lead levels was 5.4 μg/dL. In this study, behaviour was rated using the Achenbach Child Behaviour Checklist Teacher Report Form and the Barkley-DuPaul Attention Deficit Hyperactivity Disorder Scale. Associations between attention and blood lead levels were noticeable at concentrations as low as 3 μmol/dL.

The behavioural deficits found in exposed children seem to parallel those found in children with attention deficit and hyperactivity disorder (ADHD) [56], which has been linked to catecholaminergic changes in exposed children [27,33,62,63].

1.3. Effects of lead on motor function

In many studies, lead exposure has been linked to motor deficits, however such findings are somewhat inconsistent. The overall consensus is that gross motor function remains unaffected, whereas fine motor function, visual-motor function and postural sway are affected by exposure to lead [25,68]. Results on gross motor coordination are still controversial [14,41,68]. The major difficulty when trying to understand the underlying mechanisms of lead's impact on motor function is that there is no single brain area responsible for such capacities. Motor functions are likely to be affected in a variety of ways such as: (1) synapses between areas are disrupted by lead and therefore motor functions can not be properly executed; (2) lead has a direct impact on a mediating variable such as behaviour which in turn influences a variety of neurodevelopment functions [61].

1.4. Relation between behaviour and motor functions

Research in the field of child pathology indicate strong associations between behavioural deficits and the ability to perform various motor tasks. Children with ADHD seem to have deficits in kinaesthetic acuity, fine motor skills, gross motor skills, motor control, inhibition of motor responses, motor flexibility and motor preparedness [10,25,66,69]. Recent studies have found a correlation between ADHD symptoms and impaired postural stability and sway velocity when balance is tested [34,67]. Considering that children exposed to lead have been found to display behavioural and motor characteristics similar to those of children with ADHD, it is of interest to study the possible relationship between behaviour and fine motor deficits in lead-exposed children.

2. Objective

In a recent study carried out in Nunavik, Inuit children were tested at birth and later on at 5 years of age for lead (Pb), mercury (Hg) and organochlorine compounds (OCs) in blood.