**Highlights**

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Elevated Mn body burden is associated with decreased motor function, but impactsin wild animals are unknown.

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We tested the sprint speed, [manoeuvrability](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/maneuverability" \o "Learn more about manoeuvrability from ScienceDirect's AI-generated Topic Pages), and motor control of wild northern quolls exposed to Mnmining dust.

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Quolls with higher Mnlevels approached a corner at a narrower range of speeds, due to a lower maximum approach speed.

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Slower approach speeds may reflect compensation for neuromotor impairment.

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In wild animals, slower speeds approaching a turn likely reduce success at catching prey and avoiding predators.

**Abstract**

Neuromotor deficits are an important sign of manganese (Mn) toxicity in humans and laboratory animals. However, the impacts of Mn exposure on the motor function of wild animals remains largely unknown. Here, we assessed the impact of chronic exposure to Mn from active mining operations on Groote Eylandt, Australia on the motor function of the semi-arboreal northern quoll (*Dasyurus hallucatus*), an endangered species. The three motor tests conducted—maximum sprint speed on a straight run, [manoeuvrability](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/maneuverability" \o "Learn more about manoeuvrability from ScienceDirect's AI-generated Topic Pages) around a corner, and motor control on a balance beam—showed that elevated Mn body burden did not diminish performance of these traits. However, quolls with higher Mn body burden approached a corner at a significantly narrower range of speeds, due to a significantly lower maximum approach speed. Slower speeds approaching a turn may reduce success at catching prey and avoiding predators. Given that maximum sprint speed on a straight run was not affected by Mn body burden, but maximum speed entering a corner was, slower speeds approaching a turn may reflect compensation for otherwise impaired performance in the turn.

**Graphical abstract**



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**Introduction**

Movement disorder and cognitive deficit are the main symptoms of manganese (Mn) toxicity in humans (Levy and Nassetta, 2003; Josephs et al., 2005; Klos et al., 2006; ATSDR, 2012), even in non-occupational settings (Mergler et al., 1999; Rodriguez-Agudelo et al., 2006; Hernandez-Bonilla et al., 2011). Mn accumulates in the brains of humans (Calne et al., 1994; Mergler, 1999; Aschner, 2000; Aschner et al., 2005) and animals (Dastur et al., 1971; St-Pierre et al., 2001; Salehi et al., 2003; Tapin et al., 2006; Amir Abdul Nasir et al., 2018), damaging the dopaminergic neurons that control muscle movement (Aschner et al., 2005). Toxicity initially manifests as slowed motor speed and imbalanced posture when walking or rising (Cook et al., 1974; Normandin and Hazell, 2002; Bowler et al., 2006). As the condition worsens, individuals may also display gait disorders and impaired ability to perform rapid, alternating movements (Cook et al., 1974; Normandin and Hazell, 2002; Bowler et al., 2006).

In the laboratory, motor deficits have manifested in rodents and non-human primates following exposure to Mn of various chemical forms, doses and routes (Bonilla, 1984; Eriksson et al., 1987; Olanow et al., 1996; Witholt et al., 2000; Normandin et al., 2004). Mn accumulates in the brain of rats, leading to hyperactivity (St-Pierre et al., 2001; Salehi et al., 2003; Tapin et al., 2006), decreased locomotor activity, increased gait abnormalities, and impairment of the ability to traverse a balance beam (Witholt et al., 2000). Although clear evidence exists for negative impacts of Mn on motor function of animals in controlled laboratory settings, to our knowledge no studies have explored how Mn affects the motor function of animals in natural populations. Movement plays a critical role in an animal's interactions with competitors, mates, predators, and prey, and therefore is central to reproductive success and survival (Biewener, 2003; Husak and Fox, 2006; Husak et al., 2006; Wilson et al., 2007; Nathan et al., 2008; Clark and Higham, 2011). Exposure to contaminants that impact an animal's motor performance is likely to affect reproductive success and population viability, even if the contaminant does not directly cause mortality (Faimali et al., 2006).

Groote Eylandt, located in the Gulf of Carpentaria, Australia, is an Indigenous Protected Area and owned by the Anindilyakwan people. It is a site of International Conservation Significance, with 12 threatened and endangered vertebrate species including the northern quoll (*Dasyurus hallucatus*) (ALC, 2014; DOE, 2014). This island is also the site of one of the largest Mn ore producers in the world (South32 2014). The Groote Eylandt Mining Company (GEMCO, a BHP Billiton subsidiary) has operated since 1964 and produces 3–4 million tonnes of ore annually (South32, 2014; USGS, 2016). Mn is extracted from open pits and crushed onsite before it is transported in open trailers to the port for open-air storage and shipping, with vast quantities of ore dust liberated into the environment during processing. Fine, air-borne Mn dust in the respirable size range occurs on Groote Eylandt at levels exceeding international recommendations, even 20 km from the Mn extraction, processing, and storage facilities (Amir Abdul Nasir et al., 2018).

Recently, we found that northern quolls living near mining sites on Groote Eylandt accumulate substantial Mn within their hair, testes and two brain regions, the neocortex and cerebellum (Amir Abdul Nasir et al., 2018). Because the neocortex and cerebellum are responsible for sensory perception and motor function, respectively (Nelson and Armati, 2006), accumulation of Mn in these brain regions could impair sensory and motor functions of quolls. Impairment of these traits by Mn may diminish the ability of quolls and other wildlife to perform tasks related to reproduction and survival. Here, we examine how chronic Mn exposure affects the locomotor function of northern quolls on Groote Eylandt. Northern quolls are a semi-arboreal predatory species, spending time navigating both arboreal and terrestrial substrates. In these complex habitat types, quolls flee from predators (e.g., snakes, raptors and dingoes [*Canis lupus dingo*]) and chase after prey (e.g., insects, small mammals, reptiles); both require optimum motor function and strategy. We predicted that quolls exposed to higher levels of environmental Mn from mining operations would exhibit decreases in their performance of the ecologically relevant motor tasks: (1) maximum straight-line sprint speed, (2) manoeuvrability around a tight corner, and (3) motor control while running along a narrow beam. We also predicted that quolls exposed to higher levels of Mn were more likely to make mistakes (i.e. slip or crash) while performing the manoeuvrability and motor controls tasks.

**Section snippets**

**Field and laboratory procedures**

We trapped northern quolls in May–September 2014 during three separate dry-season periods: pre-breeding (weeks 20–25), breeding (weeks 28–30) and post-breeding (weeks 33–37). The breeding season was assumed to have started when trapped female quolls began showing breeding scars, which are caused by male aggression during copulation. We trapped at seven sites proximate to mining sites where Mn is extracted and crushed, and the port, where Mn is stored in open-air prior to shipping. We also

**Maximum sprint speed**

Maximum sprint speed (n = 128) differed significantly between seasons in the most parsimonious sub-models that included PC2ElementLoad (0.06 *wi*, *F*(2,124) = 3.231, *p* = 0.043) and hair[Mn] (0.06 *wi*, *F*(2,124) = 3.838, *p* = 0.024), though it did not show a direct, significant relationship with either PC2ElementLoad or hair[Mn] (Table S1 (A)). Maximum sprint speed did not differ between sexes (n = 65 females, 63 males; *p* > 0.05; one-way ANOVA) but was significantly lower in post-breeding than in

**Discussion**

The neurological effects of elevated Mn exposure have been extensively studied in humans and laboratory animals, but the extent to which Mn toxicity affects wildlife in their natural habitat remains largely unknown. We assessed how the motor function of wild northern quolls was affected by exposure to chronic environmental Mn, as estimated using Mn concentration in their hair. Because Mn ore excavation and processing releases fine dust containing a variety of elements, including other toxic

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Research data for this article

*Data not available / Data will be made available on request*

[Further information on research data](https://service.elsevier.com/app/answers/detail/a_id/35539/c/10546/supporthub/sciencedirect/)

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2022, Science of the Total Environment

Citation Excerpt :

Though the presence and movement of metals at tailings storage facilities are frequently reported, the exposure pathways to wildlife inhabiting rehabilitated sites are infrequently studied, and the risks rarely quantified (Cross et al., 2019). In particular, the effects of metals from mining on marsupials have been rarely studied, with only two papers regarding the effect of Mn on northern quolls (Dasyurus hallucatus) at a Mn mine in the north of Western Australia (Amir Abdul Nasir et al., 2018a; Amir Abdul Nasir et al., 2018b). The colonisation of the Royal George tailings by wombats presents an opportunity to examine metal transfer from mine tailings to an herbivorous fossorial marsupial.

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* [An alkali modified biochar for enhancing Mn<sup>2+</sup> adsorption: Performance and chemical mechanism](https://www.sciencedirect.com/science/article/pii/S0254058420302741)

2020, Materials Chemistry and Physics

Citation Excerpt :

In recent years, the process effluents with excessive amounts of soluble Mn2+ from coal mining and electrolysis activities are polluting natural water bodies [2,3]. Continuous charge of Mn would increase the health risk by causing neurological deficits and pulmonary disorders to organisms [4,5]. Drinking water taken from groundwater and surface water is one of the main sources of Mn toxicity in humans [6].

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* [Suburban areas in flames: Dispersion of potentially toxic elements from burned vegetation and buildings. Estimation of the associated ecological and human health risk](https://www.sciencedirect.com/science/article/pii/S0013935120300451)

2020, Environmental Research

Citation Excerpt :

Because Mn exceeds EPA (RS,P,A,M), there is a potential risk to human health and terrestrial ecological receptors. Amir Abdul Nasir et al. (2018) concluded that Mn contamination affects the motor performance, reproductive success and survival of an animal (Dasyurus hallucatus) which is included in the endangered vertebrate species of Australia. Kasprzak et al. (2003) concluded that Ni causes skin allergies and affects the pulmonary system.

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