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Physiology & Behavior

journal homepage: www.elsevier.com/locate/physbeh

Parental hormones are associated with crop loss and family sickness following catastrophic flooding in lowland Bolivia

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ARTICLE INFO

Keywords:

Testosterone

Cortisol

Natural disaster

ABSTRACT

The physiology of fatherhood is a growing field of study, and variability in hormonal mediators of reproductive effort (e.g. testosterone, cortisol) can predict variability in paternal investment. Studies often find that lower testosterone levels are associated with increased paternal investment, though most studies are conducted under relatively stable ecological conditions. In this paper, we examine parental physiological correlates of crop loss and family health problems among Tsimane forager-horticulturalists following a catastrophic flood in lowland Bolivia. Immediately after a devastating 2014 flood that impacted > 75% of Tsimane communities, we conducted structured interviews examining crop losses and morbidity, and collected saliva specimens from 421 parents (n = 292 households) to analyze cortisol and testosterone. Over 98% of interviewees reported horticultural losses, with the average family losing 88% of their crops, while 80% of families reported flood-induced injuries or illnesses. Controlling for age, body mass index, and time of specimen collection, men's testosterone was negatively associated with both absolute cropland losses (Std. $\beta = -0.16$, $p = 0.037$), and percent of cropland lost (Std. $\beta = -0.16$, $p = 0.040$). Female testosterone was not associated with crop losses. Using the same control variables, both male and female cortisol was negatively associated with a composite measure of child health burden (fathers: Std. $\beta = -0.34$, $p < 0.001$; mothers: Std. $\beta = -0.23$, $p = 0.037$). These results are discussed in the cultural context of a strong sexual division of labor among Tsimane; we highlight the physiological and psychosocial costs of experiencing a natural disaster, especially for paternal caregivers in a nutritionally and pathogenically stressed subsistence population where cultigens provide the majority of calories in the diet.

1. Introduction

Natural disasters (e.g. flooding, drought) are often part of broader ecological shifts that precede evolutionary change, including the origin of the genus *Homo* [1,2]. The human commitment to extensive resource transfers between and within generations [3–5] likely mitigated deleterious fitness effects of historically common environmental shocks. While most anthropological research in small-scale foraging and mixed foraging-horticultural societies has focused on ways in which individuals cope with variability in daily resource acquisition [3,5,6], much less is known about how individuals cope with natural disasters

that impact large geographic areas and segments of the population. The irregular occurrence of natural disasters, logistical difficulties of accurately assessing losses from and responses to disasters in remote areas, and the fact that behavioral and physiological responses are not preserved in the fossil record all make it difficult to infer how individuals in small-scale societies cope with natural disasters. To date, little is known about physiological and behavioral effects of natural disasters, or the extent of resilience in small-scale societies operating largely “off-the-grid”.

In this paper we: i) document crop losses and family health problems (i.e. illness and injury) following a recent catastrophic flood in

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<https://doi.org/10.1016/j.physbeh.2018.02.028>

Received 19 August 2017; Received in revised form 12 February 2018; Accepted 14 February 2018
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lowland Bolivia among Tsimane forager-horticulturalists and ii) examine physiological correlates (i.e. testosterone and cortisol) of crop loss and family health problems among Tsimane parents. Hormones such as testosterone and cortisol are often used to track levels of physiological or psychological arousal [7]. Testosterone is associated with paternal investment in humans and other primates [8–12], and its relationship to family stress, including crop loss and family illness and injury, is of interest to the growing field of research examining the physiology of parenting. New methods of quantifying male physiological investment using hormonal activity have recently become possible, providing insight into individual-level variation in men's responses to young children [8,13,14]. Relevant studies show that high-investing fathers have lower levels of testosterone than lower-investing fathers [10,14]. However, most of these studies focus on fatherhood during relatively stable environmental conditions, and thus little is known about the physiology of parenthood following a major environmental shock. Several studies have examined associations between cortisol and psychosocial stress following traumatic events [15–17], and while the literature on this theme is still in its infancy, these studies represent an important step toward understanding how shocks such as natural disasters influence human physiology and behavior.

In January and February of 2014, historic floods severely impacted populations residing in lowland Bolivia (Beni Department), including Tsimane Amerindians, who practice a subsistence lifestyle based on horticulture, fishing and hunting [18]. During and immediately following the flood, hundreds of Tsimane families fled to higher ground deep in the forest, or to makeshift encampments in the nearby market town of San Borja (population ~ 25,000). Many homes and possessions in Tsimane villages were abandoned during the rush to escape rising waters of the Maniqui river, which overflowed with little or no warning. Tsimane Health and Life History Project (THLHP) data indicate that > 60 Tsimane villages flooded, with large-scale crop losses affecting nearly all residents. Local media sources, focused their narratives on impacts of flooding among residents of nearby market towns (e.g. San Borja, Rurrenabaque, Yucumo), and reported approximately 60 people and 400,000 livestock were killed, 63,000 ha of crops (e.g. rice, plantain, manioc, corn) were destroyed, and 60,000 families were affected [United Nations [19], International Red Cross [20]]. While smaller scale, localized flooding is common in this tropical region, the 2014 flood was the worst experienced in decades [21] due to recent La Niña and El Niño weather patterns, triggering pervasive food insecurity, disease and injury.

Adverse life events including natural disasters can have profound, long-term hormonal impacts [22] and lasting health consequences [23,24]. While there is a great deal of variation in the type, frequency and severity of adverse life events, human [24], non-human primate [25], and other mammalian models routinely show changes in hypothalamic-pituitary-adrenal (HPA) and hypothalamic-pituitary-gonadal (HPG) activity following a range of adverse life events [24,26]. These impacts often are measured via hormonal dysregulation, either via altered baseline levels, changes in acute hormonal stress responsiveness, or disrupted diurnal variation [16].

This manuscript aims to integrate two parallel literatures; the physiology of parenthood, and hormonal changes following a natural disaster. When disasters occur, they do not just strike single individuals, but disrupt the lives of everyone in a population, especially for families already on the margins of society. Here we examine how disaster impacts the physiology of parental care givers, bridging these two diverse literatures in the context of a major flood.

1.1. Hypotheses

Adverse events can disturb many aspects of physiology, and changes in HPA activity are the most extensively studied [16,22,24]. Many studies report that individuals exposed to major traumatic experiences (e.g. warfare, genocide) who develop post-traumatic stress disorder

(PTSD) show low baseline cortisol levels [15,17,27–29], though see [30]. Psychologically treating PTSD patients with low cortisol levels can increase those levels, suggesting that in some cases cortisol is depressed by repeated stressors or traumatic experiences [31]. The type of stressors, timing of stressor exposure over the life course, intensity and duration of stresses vary across studies, making comparisons difficult [15,30]. In addition, links between cortisol levels and experience of a natural disaster are relatively understudied, especially in populations like the Tsimane who experience various stressors on a daily basis (e.g. high pathogen burden, food insecurity, poverty) [32]. Relevant literature from high income countries (e.g. Japan) indicates that individuals more affected by a major earthquake had lower cortisol [17]. Relatedly, a study of wildfire survivors in Southern California found that individuals with more PTSD symptoms had blunted cortisol [33]. In light of this limited but suggestive evidence, we hypothesize that Tsimane parents who experience greater destructive impacts of flooding, as indicated here by crop losses and threats to family health, will have lower cortisol levels.

In addition to changes in cortisol, we expect severity of the destructive impact of flooding to be associated with lower testosterone, both for physiological and psychosocial reasons. As subsistence horticulturalists, households facing significant crop losses are also likely to experience food insecurity. Psychologically, food insecurity and relative deprivation can be very damaging. From a physiological standpoint, fasting [34], even for short time periods results in immediate decreases in circulating testosterone [35]. In addition to the impacts of food deprivation, illness and injury can downregulate testosterone production [36–38], and immune responses to pathogenic stress are also associated with depressive symptoms [38,39].

From a psychosocial standpoint, when individual and/or group-level status is enhanced (e.g. from winning a competition), testosterone transiently increases in males [40–42] and females [43], and then begins to return to normal levels within an hour [44]. In contrast, testosterone decreases for men who experience even minor losses in athletic or social competition [45–47]. While researchers have not yet examined how long this decline in testosterone lasts following a sports loss, lower levels of testosterone are associated with depressive symptoms in cases of both acute and chronic depressive symptoms [48,49]. While testosterone is associated with many aspects of male biology and psychology such as investment in offspring [8–10,12,14,50], testosterone is not generally associated with maternal behavior in females where other hormones like oxytocin play an important role in mother-infant bonding [7]. In light of this evidence, we expect that men who experience greater destructive impacts of flooding (indicated by crop losses and threats to family health) will have lower levels of testosterone.

2. Methods

2.1. Flood interview and anthropometry

Lowland Bolivian floodwaters peaked in mid-February 2014. As flood waters receded, the THLHP's mobile medical team, with funding from an NSF RAPID grant and private donations to the Tsimane Flood Relief fund, visited 25 Tsimane communities to deliver donations (e.g. horticultural tools) to help people rebuild. After giving donations, mobile team anthropologists conducted interviews regarding crop losses and family health from March 14th–30th, 2014 (eligibility for receiving donations were not contingent on being interviewed). Household heads and/or their spouses reported the total number of tareas (a local measure of area equivalent to 629 m², one-tenth of a hectare) of each of the four staple crops (rice, plantains, manioc and corn) they possessed before the flood, and the total number of tareas that remained viable following flooding. From these data we created two indices: i) absolute number of crops lost across all four staples; and ii) percentage of total tareas of crops lost across all four

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