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Developmental instability and its relationship to mental health in two historic Dutch populations

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ABSTRACT

This study aimed to assess the magnitude and patterns of fluctuating asymmetry as an indicator of developmental instability between two urban archeological Dutch populations. The sample comprised of 209 adult individuals representing the general population of Alkmaar, the Netherlands, dating to the 18th to early 19th century (Grote Kerk, $n = 134$), and a psychiatric hospital sample of the 19th to early 20th century (Meerenberg, $n = 75$). Fluctuating asymmetry was assessed from left and right measurements recorded from various traits on the cranium, mandible, and dentition. Three non-specific skeletal indicators of stress were documented to aid in the interpretation of the differences in asymmetry. No significant difference in developmental instability, as reflected by fluctuating asymmetry, was apparent between the two populations. However, individuals who presented with skeletal lesions indicative of stress were significantly more asymmetric than individuals who did not present with any of the lesions. The observed frequencies of the pathological changes and socio-economic history suggest that the two populations experienced similar levels of stress, even though the source and duration of the stress might have been different. The possibility that the mentally institutionalized are not as developmentally unstable as suggested by previous research should be considered.

1. Introduction

Developmental homeostasis and two of its components, developmental stability and canalization, are important for the attainment of bilaterally symmetrical anatomical structures during ontogeny (Møller and Swaddle, 1997). Developmental stability refers to the inherent ability of an organism to resist random errors or stressors under specific internal (genetic) and external (environmental) conditions (Møller and Swaddle, 1997; Palmer, 1994). Bilateral structures or traits, such as the left and right orbits, are products of a common gene complex with identical developmental pathways. Should developmental homeostasis be maintained throughout development, the phenotypic expression of this identical genotype will result in identical phenotypes that are bilaterally symmetrical (Palmer and Strobeck, 2003; Van Valen, 1962). However, when changes in the internal and external conditions of development occur, canalization acts as a buffer or regulator to these changes to ensure that developmental homeostasis is maintained and that the intended developmental pathway is followed (Møller and Swaddle, 1997; Waddington, 1957, 1942). The inability to maintain homeostasis due to developmental instability or ineffective canalization will lead to bilateral asymmetry of a structure or trait (Van Valen, 1962).

Three types of bilateral asymmetry are described in the literature: fluctuating asymmetry (FA),[1] directional asymmetry (DA) and antisymmetry. Antisymmetry and DA of a trait are usually associated with behavioral factors, also referred to as adaptive asymmetries. In DA a morphological trait in a population will express a constant greater increase in development on either the right or the left side of the plane of symmetry, whereas in antisymmetry, the preference in increased size toward any one side within a population will be random, resulting in bimodal symmetry around a mean of zero (Palmer, 1994; Van Valen, 1962). Fluctuating asymmetry, on the other hand, has mainly been linked to developmental instability, and is defined as the morphological inequality of bilateral anatomical structures such that the average expression of individual asymmetries per trait in a population will be symmetrical (Møller and Swaddle, 1997; Palmer, 1994; Van Valen, 1962). This paper will focus on FA and its utilization as an indicator of developmental instability within past populations.

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[1] *Abbreviations*: FA: fluctuating asymmetry; DA: directional asymmetry; GRK: Grote Kerk population; MeB: Meerenberg population; ME: measurement error.

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While FA has been utilized in a vast number of studies as an indicator of developmental instability, its reliability for such purposes has been questioned (Bjorksten et al., 2000; e.g. Black, 1980; Gawlikowska et al., 2007). The support for its use as an indicator of developmental instability seems to be based on positive relationships between FA and environmental, genetic, and other indicators of stress. The majority of literature on FA in human archeological remains, specifically on the cranium and dentition, revealed increased levels of FA that coincided with lower socio-economic status, malnutrition, higher mortality rates, retarded growth during late childhood, and higher frequencies of enamel hypoplasia (EH) and cribra orbitalia (Bailit et al., 1970; DeLeon, 2007; Guatelli-Steinberg et al., 2006; Harris and Nweeia, 1980; Perzigian, 1977; Storm, 2007; Weisensee, 2013). For example, Storm (2007, 2008) found increased levels of FA in human archeological remains from the Medieval to the Victorian periods in England that coincided with the environmental and social changes brought on by the British Industrial Revolution. Additional comparative analyses, based on the socio-economic status (SES) of a number of the archeological populations, revealed higher levels of FA in the populations of lower SES, further supporting the premise that FA, and inherently developmental instability, increases with adverse external or environmental conditions. However, in other studies, the relationship was either not significant (Arnqvist and Thornhill, 1998; Bjorksten et al., 2000; Gawlikowska et al., 2007), or only evident for a minority of traits (Hoover and Matsumura, 2008).

The positive relationship between FA and levels of stress is based on the premise that various external and internal factors, termed developmental noise or stress, can negatively and additively affect developmental homeostasis (Møller and Swaddle, 1997; Van Valen, 1962). Complete bilateral symmetry will only occur when developmental homeostasis sufficiently buffers the developmental stresses during development, or in other words when the developmental pathways are highly canalized. When the developmental stress or stressors are greater than the threshold level or buffering ability of a trait, the original phenotypic expression of the genotype will not be reached, resulting in bilateral asymmetry or FA of a trait. It follows that the less canalized a certain developmental pathway or the greater the developmental instability, the greater the amount of FA will be (Adams and Niswander, 1967; Palmer and Strobeck, 2003; Storm, 2008; Waddington, 1942).

Chronic periods of certain environmental stressors, such as malnutrition or nutritional deficiencies, infection, and other factors or illnesses related to low SES or economic hardship, are known to cause pathological lesions on dry bone and dentition, such as periostitis, EH, cribra orbitalia and porotic hyperostosis (Mann and Murphy, 1990; Reitsema and McIlvaine, 2014). However, some of these indicators of stress, such as EH, have also been associated with syndromes and congenital disorders, and can be attributed to the mutation of several developmental regulatory genes, or in other words, internal or genetic stress (Brook, 2009; Schuurs, 2013; Seow, 1997).

A factor that has been linked to decreased developmental stability in a group of individuals relative to the rest of the population is mental and neurological deficiencies or disorders. A vast number of studies (Malina and Buschang, 1984; Markow and Gottesman, 1989; Markow and Wandler, 1986; Martin et al., 1999; Reilly et al., 2001; Shackelford and Larsen, 1997) have associated various mental disorders and neurological impairments in living individuals with an increase in developmental instability and increased levels of asymmetry. Cerebral palsy, schizophrenia, and depression in men are some of the disorders that have been associated with decreased developmental stability. Perhaps the most relevant asymmetry study on the relationship between mental status and FA was conducted by Malina and Buschang (1984) on living males. In this study, eleven bilateral measurements were collected on 200 males with a history of mental disorders and/or neurological impairments (aged nine to 52 years), and on 202 mentally healthy males ranging from five to 35 years of age. The comparison revealed an overall higher magnitude of asymmetry within the males with mental disorders, with significant differences in the upper limb measurements.

Due to their alleged decreased developmental stability, it can be speculated that individuals with a history of mental disorders or neurological impairments will exhibit greater magnitudes of FA relative to the general ('mentally healthy') population when subjected to equal types and levels of stress. A search of the literature revealed no previous studies between FA and mental health in skeletal samples.

In light of the abovementioned hypothesis that individuals suffering from a mental or neurological disorder will exhibit greater levels of FA relative to the general population, this study aimed to compare the level of developmental stability and stress between two Dutch archeological populations by means of an assessment of the magnitude of FA in the cranium, mandible and dentition. One population represents the general population, while the other population represents individuals buried in the graveyard of a former Dutch mental institution.

2. Materials and methods

2.1. Skeletal samples

This study was conducted with research and ethical approval obtained from the Academic Medical Centre (AMC), University of Amsterdam, and the Faculty of Health Sciences Research Ethics Committee, University of Pretoria (393/2014), respectively. The skeletal sample investigated comprised of 209 adult individuals from two Dutch archeological populations, 134 from Grote Kerk (GRK) and 75 from Meerenberg (MeB). Both skeletal collections are housed at the AMC in Amsterdam, the Netherlands.

The GRK sample dates to the 18th and early 19th century and was excavated from the church floor of the St. Laurenskerk in Alkmaar, the Netherlands. Burial underneath church floors was customary in the Netherlands from the Middle Ages to the late 1820's, after which it was banned by law. Church burials were substantially more expensive than burials within graveyards and were mainly a custom that families of middle to high SES could afford. However, burial within the church of Alkmaar only became excessively expensive by the end of the 18th century (Baetsen, 2001; Baetsen et al., 1997; Bitter, 2002).

The MeB sample was excavated from a Catholic cemetery of the historic Meerenberg psychiatric hospital in Bloemendaal, the Netherlands. Sixty-six graves were exhumed during a rescue excavation after the accidental disturbance of the graves by property development in 2009. The graves dated from 1891 to 1914, and the individuals within the sample likely lived during the early 19th to the early 20th century (Van der Merwe et al., 2013). The Meerenberg psychiatric hospital was established during the 1840's. During the 19th century, Meerenberg was one of the largest and most prestigious mental asylums in the Netherlands, housing chronic patients with more advanced levels of mental disorders or neurological impairments relative to the other mental asylums (Goldberg and Graham, 2013; Van Twuyver, 2000; Vijselaar, 1982). Both patients and staff members were buried in the cemeteries on the Meerenberg grounds (Van Twuyver, 2000).

2.2. Methods

Twenty-four bilateral measurements from the cranium and mandible, and two bilateral measurements on all permanent teeth, except the third molars, were chosen for an evaluation of the developmental instability between the two populations. The measurements and their definitions are indicated in Fig. 1.

All measurements were based on previously defined measurements and procedures for dry bone (Buikstra and Ubelaker, 1994; Howells, 1973; Storm, 2009) and dentition (Guatelli-Steinberg et al., 2006; Kieser, 1990), except for three cranial measurements specifically defined for FA analyses by Storm (2009). The latter measurements

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