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Heritability of the affective response to exercise and its correlation to exercise behavior

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A R T I C L E I N F O

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A B S T R A C T

Objectives: Individual differences in adolescent exercise behavior are strongly influenced by genetic factors. The affective response to exercise is a potential source of these genetic influences. To test its role in the motivation to exercise, we estimated the heritability of the affective responses during and after exercise and the overlap with the genetic factors influencing regular voluntary exercise behavior.
Design: 226 twin pairs and 38 siblings completed two submaximal exercise tests on a cycle ergometer and a treadmill and a maximal exercise test on a cycle ergometer. Affective responses were assessed by the Feeling Scale (FS), Borg's Rating of Perceived Exertion (RPE) and the Activation-Deactivation Adjective Checklist (AD ACL).
Methods: Multivariate structural equation modeling was used to estimate heritability of the affective responses during and after submaximal and maximal exercise and the (genetic) correlation with self-reported regular voluntary exercise behavior over the past year.
Results: Genetic factors explained 15% of the individual differences in FS responses during the cycle ergometer test, as well as 29% and 35% of the individual differences in RPE during the cycle ergometer and treadmill tests, respectively. For the AD ACL scales, heritability estimates ranged from 17% to 37% after submaximal exercise and from 12% to 37% after maximal exercise. Without exception, more positive affective responses were associated with higher amounts of regular exercise activity ($0.15 < r < 0.21$) and this association was accounted for by an overlap in genetic factors influencing affective responding and exercise behavior.
Conclusions: We demonstrate low to moderate heritability estimates for the affective response during and after exercise and significant (genetic) associations with regular voluntary exercise behavior. These innate individual differences in the affective responses to exercise should be taken into account in interventions aiming to motivate adolescents to adopt and maintain regular exercise.

1. Introduction

Regular physical activity is a key contributor to adolescents' health (Janssen & Leblanc, 2010). However, the majority of youngsters does not engage in regular exercise at the recommended level, despite efforts of governments and health care organizations promoting exercise (Martinez-Gonzalez et al., 2001; Troiano et al., 2008). To create a successful intervention, one must have knowledge about the underlying predictors of a physically active lifestyle. One of the potential motivational mechanisms underlying exercise behavior is the affective response immediately during exercise and shortly after cessation of an exercise bout (Ekkekakis, Parfitt, & Petruzzello, 2011, 2013).

Affect refers to an individual's core of all valenced states: good versus bad, pleasure and displeasure, positive and negative

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(Ekkekakis et al., 2011, 2013). In contrast to the persistent general belief that exercise is enjoyable for everyone, strong individual differences are found in the affective responses during and after exercise. Whereas some individuals indeed report an increase in pleasure or no change, others report reduced pleasure or negative changes in affect (Ekkekakis, Hall, & Petruzzello, 2005, 2011; Van Landluyt, Ekkekakis, Hall, & Petruzzello, 2000; Welch, Hulley, Ferguson, & Beauchamp, 2007). Based on the principles of instrumental conditioning, the repeated affective responses to exercise activities could be a powerful determinant of the formation of stable behavioral habits. If the affective response is on balance positive, people are likely to maintain the behavior and become regular exercisers. However, if the net affective response is not favorable, people are at risk of dropping out and becoming non-exercisers. In keeping with this theoretical expectation, a more favorable affective response during exercise was found to be associated with the intention to engage in voluntary exercise (Kwan & Bryan, 2010; Ruby, Dunn, Perrino, Gillis, & Viel, 2011) and greater actual participation in (voluntary) moderate to vigorous exercise (Dunton & Vaughan, 2008; Rhodes & Kates, 2015; Schneider, Dunn, & Cooper, 2009; Williams et al., 2008, 2012). A better understanding of the determinants of the affective response to exercise may therefore be paramount to creating successful exercise interventions.

The net affective response during and shortly after exercise may reflect a mixture of multiple aversive and appetitive effects. Examples of immediate aversive effects are exercise-related fatigue related to muscle pain, respiratory exertion and monoamine depletion (Davis & Bailey, 1997). After exercise, cardiovascular activation levels may be uncomfortably high for a prolonged period, paired to lingering muscle fatigue and central fatigue (Ament & Verkerke, 2009). More complex aversive effects may involve the fear for embarrassment and injuries (Huppertz et al., 2014b; Rhodes et al., 1999; Skelton & Beyer, 2003; Vartanian & Shaprow, 2008). These aversive effects may be balanced by the rewarding effects which are governed by the mesolimbic reward system that involves dopaminergic pathways (Beaulieu & Gainetdinov, 2011). More complex appetitive effects can involve a sense of accomplishment or distraction from worry or feelings of anxiety (Anderson & Shivakumar, 2013) during but also after exercise cessation. Shortly after exercise activities, sympathetic withdrawal may temporarily reduce the physiological sensitivity to stress (Chen & Bonham, 2010; Hsu et al., 2015).

de Geus and de Moor (2008) have hypothesized that these individual differences in part reflect differences in genetic sensitivity to the psychological effects of exercise (de Geus & de Moor, 2008). A significant genetic contribution of the affective responses to exercise could explain the now well-documented heritability of voluntary exercise behavior which peaks at 82% in late adolescence (Huppertz et al., 2012) and remains in play throughout adulthood with heritability estimates of around 42% (de Moor et al., 2011). Genetic variants influencing the affective exercise response could do so in part by an effect on the so-called 'activity drive' (Lerman et al., 2002; Lightfoot, Turner, Daves, Vordermark, & Kleeberger, 2004; Rowland, 1998). This activity drive can be conceptualized as an innate motivation to be physical active in the classical Hullian sense, not different from sex drive, hunger or thirst. Just as the glucostat cells and the baroreflex that keep sugar and blood pressure level constant at an optimal level, the activity-stat could keep a person's energy expenditure at an optimal level, but that level may differ significantly across individuals dependent on genotype (Lightfoot et al., 2004; Swallow, Carter, & Garland, 1998). The activity-stat could influence the net balance of positive and negative affective responses during and after a bout of exercise as the fulfillment of drives is intrinsically rewarding.

Other factors known to influence exercise behavior could further modulate the affective response to exercise. Positive attitudes and expected health benefits may lead the individual to endure an unfavorable balance between the aversive and appetitive effects, as may a strong ability to self-regulate. Both self-regulation traits and attitude are associated with exercise behavior and/or physical activity (Dishman, Jackson, & Bray, 2014; Dishman, McIver, Dowda, Saunders, & Pate, 2015; Hagger, Chatzisarantis, & Biddle, 2002). Moreover, attitudes have been shown to be heritable (Huppertz et al., 2014b) and the psychological concept of self-regulation is also under substantial genetic control (Posner & Rothbart, 2009). Increased sensitivity to punishment as seen in neuroticism, aversion to arousal as seen in introversion, or reward-seeking behavior as seen in extraversion and sensation seeking, all heritable personality traits, may further modulate the affective response to exercise accounting for the association of personality with exercise behavior (de Moor, Beem, Stubbe, Boomsma, & de Geus, 2006).

A final important contributor to the net affective response to exercise is exercise ability and/or trainability. Activities that one is good at are likely to be pursued in leisure time. Performing better at exercise than others, or gaining more rapidly when exposed to comparable training regimes, will lead to feelings of competence, whereas lower levels of performance and trainability might lead to disappointment or shame (particularly when the exercise is performed in a competitive context). A large body of literature has confirmed self-efficacy, the belief and conviction that one can perform a given activity at an adequate level of performance, is a powerful determinant of whether someone engages in and adheres to an exercise program (Dishman et al., 2005; McAuley & Blissmer, 2000; Nigg, 2001). Self-efficacy may be an especially strong factor in adolescence, when the sensitivity to one's own relative ranking among peers may be largest.

The present study aims to test the hypothesis that the affective responses during and after exercise show significant heritability in adolescence. Secondly, it aims to test the hypothesis by de Geus and de Moor (2008) that the genetic factors underlying this heritability partly overlap with the genetic factors underlying regular voluntary exercise behavior. To test these two hypotheses, the affective state was repeatedly measured in a large adolescent sample of twins and siblings during and after graded (sub)maximal exercise tests. Regular voluntary exercise behavior over the past year was characterized in these participants by a lifestyle interview. In a twin study, the intrapair resemblance for a trait is compared between genetically identical (monozygotic, MZ) and non-identical (dizygotic, DZ) twins. We expect that MZ twins resemble each other more than DZ twins in affective responses to exercise, providing evidence for genetic influences on this response. In a bivariate extension of the twin design, cross-trait/cross-twin correlations can be further used to compute the correlation between genetic factors influencing these two traits. We expect a significant genetic correlation between adolescent exercise behavior and the exercise-induced affective response showing that they are influenced by shared genetic factors.

2. Methods

2.1. Subjects

Healthy adolescent twin pairs aged between 16 and 18 and their siblings (age range 12–25) from the Netherlands Twin Register (Van Beijsterveldt et al., 2013) were invited to participate in a study on the determinants of adolescent exercise behavior. A complete dataset was available for 499 subjects: 115 monozygotic pairs (MZ) and 111 dizygotic pairs (DZ), and 35 of their singleton siblings. Six