Hormones and Behavior 69 (2015) 50–58

Contents lists available at ScienceDirect

Hormones and Behavior

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

Regular article

Sex difference in the relationship between salivary testosterone and inter-temporal choice

Hirokazu Doi, Shota Nishitani, Kazuyuki Shinohara *

Graduate School of Biomedical Sciences, Nagasaki University, Nagasaki, Japan

ARTICLE INFO

Article history:
Received 19 May 2014
Revised 11 December 2014
Accepted 12 December 2014
Available online 19 December 2014

Keywords:
Inter-temporal choice
Discounting
Testosterone
Sex difference
Reward

ABSTRACT

Humans often prefer a small immediate reward to large reward in the future. This myopic tendency in inter-temporal choice is termed delay discounting, and has been the focus of intensive research in the past decades. Recent studies indicate that the neural regions underlying delay discounting are influenced by the gonadal steroids. However, the specific relationship between the testosterone levels and delay discounting is unclear at this point, especially in females.

The present study investigated the relationship between salivary testosterone concentrations and discounting rates in delay- and probability-discounting tasks with healthy males and females. The results revealed a positive correlation between testosterone concentrations and delay-discounting rates in females and a negative correlation in males. Testosterone concentrations were unrelated to probability-discounting rates. Although causal effects of testosterone cannot be certain in this correlational study, if testosterone directly influenced this behavior, observed sex differences in delay discounting may be evidence of a curvilinear effect of testosterone. Alternatively, the findings may reflect inverse pattern of responsiveness to testosterone between male and female neural systems, or basic sex-difference in the neural mechanism underlying delay-discounting independent of testosterone itself.

Introduction

Humans share a universal tendency to value an immediate reward more highly than a larger reward in the future (Green et al., 2004; Jimura et al., 2009). That is, the subjective evaluation of a reward is discounted according to the delay in reward delivery; the longer the delay in reward delivery, the larger becomes the degree of discounting. This seemingly irrational tendency, often observed during inter-temporal choice, is termed "delay discounting" (DD). For example, people frequently succumb to strong urges to eat high-calorie, fat-saturated foods for immediate pleasure (immediate reward), ignoring the benefit of fitness and health in the future (delayed reward). A lack of premeditation regarding future consequences and weak self-control as observed in such everyday situations are considered to be fundamental elements of addiction (Marsch and Bickel, 2001). As such, the mechanisms underlying DD in inter-temporal choice have been a topic of intensive research during the past few decades (Mischel, 1961; Kirby and Maraković, 1996; Shamosh et al., 2008). In a typical DD experiment, two alternatives, *i.e.* a smaller immediate reward and a larger delayed reward, are presented to participants. DD rate, the steepness of discounting of future reward, is estimated on the basis of participant's responses to different pairings of delay and reward. Importantly, previous studies have shown that individual differences in DD rate predict behaviors outside the laboratory. For example, a lower DD rate has been linked to a higher academic achievement, indicating that DD rate can predict levels of effort and perseverance devoted to attaining an improved future outcome (Kirby et al., 2002, 2005). Likewise, previous studies have revealed links between large DD rates and dysfunctional behaviors, like pathological gambling and substance abuse (Kirby and Petry, 2004; Green and Myerson, 2004).

Previous studies have identified a number of factors, which potentially exert influences on DD rate, such as working memory capacity (Hinson et al., 2003), intelligence (de Wit et al., 2007), reward sensitivity (Appelhans et al., 2011) and mood (Imhoff et al., 2014; Rounds et al., 2007; Worthy et al., 2014). In addition to these, many existing studies assumed, implicitly or explicitly, the link between DD rate and impulsivity (Evenden and Ryan, 1996; Kirby et al., 1999), although there is some controversy over the validity of such assumption (Reynolds et al., 2006). "Impulsivity" is a multifaceted phenomenon that includes discrete impulsivity-related behaviors/personalities (Whiteside and Lynam, 2001; Evenden, 1999; Swann et al., 2002). Among the four components of impulsivity classified by Whiteside and Lynam (2001), the lack of premeditation is closely related, conceptually speaking, to DD. Likewise, Figner et al. (2010) have revealed that suppression of the dorsolateral prefrontal cortex leads to an increased DD rate, which indicates a relationship between DD and low self-control (see also, Evenden and

* Corresponding author at: 1-12-4 Sakamoto-cho, Nagasaki City, Nagasaki 852-8523, Japan. Fax: +81 95 819 7036.
E-mail address: kazuyuki@nagasaki-u.ac.jp (K. Shinohara).

http://dx.doi.org/10.1016/j.yhbeh.2014.12.005
0018-506X/

Ryan, 1996). Therefore, although some studies have failed to establish a link between self-reported impulsive behaviors and DD (Reynolds et al., 2006), it seems likely that DD reflects aspects of impulsivity-related tendencies, which are not necessarily captured in self-reports or by other laboratory measures.

There are several lines of evidence indicating a potential link between testosterone and DD. In humans, several previous studies have revealed a link between testosterone levels and various aspects of impulsivity-related tendencies, such as aggression (Dabbs and Hargrove, 1997; Kouri et al., 1995), weak inhibitory control (Bjork et al., 2001), harmful risk-taking (Booth et al., 1999) and the personality-traits of sensation-seeking (Campbell et al., 2010; but see, Rosenblitt et al., 2001). Also, neuroimaging studies have indicated that activation of impulsivity-related neural regions, such as the reward system, the amygdala, and the prefrontal executive regions (Ballard and Knutson, 2009; Hariri et al., 2006; McClure et al., 2007; Onoda et al., 2011; Figner et al., 2010), is modulated by endogenous levels of testosterone (Wood, 1996; Packard et al., 1998). The strength of the functional connectivity among these regions is also susceptible to the influence of testosterone administration (van Wingen et al., 2010). In addition to the putative link between testosterone and impulsivity-related behaviors, previous studies have indicated that other aspects of psychological processes and personality traits like sensitivity to monetary reward, which presumably influence DD, are also modulated by testosterone level (de Macks et al., 2011; Hermans et al., 2010). Taken together, these findings could indicate that the level of bioactive testosterone might be linked to other impulsivity-related behaviors including DD as well.

The previous studies mentioned above indicate the possibility that DD may be linked to testosterone. However, this link is not particularly clear, especially regarding human studies. Ortner et al. (2013) reported that the exogenous administration of testosterone did not influence DD rates in males. Likewise, Peper et al. (2013) failed to show a direct relationship between testosterone levels and DD behavior, although they succeeded in demonstrating a link between testosterone levels and the strength of frontostriatal connectivity. Even among studies that found a relationship between testosterone and DD, the directionality of this relationship is not straightforward. Takahashi et al. (2006) found that the relation between testosterone and DD rates in male adults depended on the discounting rate *per se* in this population. More specifically, testosterone enhanced DD of gain in relatively non-impulsive males, while the opposite was observed for more impulsive individuals. DD of loss was not related to testosterone level. In sum, researchers have not reached an agreement regarding the precise nature of the relationship, if any, between testosterone level and DD.

Inconsistencies within the literature might be due to a nonlinear relationship between testosterone and DD rate; some previous studies have found a curvilinear relationship between testosterone levels and cognitive performance (Gouchie and Kimura, 1991; Moffat and Hampson, 1996; Sapienza et al., 2009; Tan and Tan, 1998). For example, Moffat and Hampson (1996) found a positive linear correlation between testosterone and spatial ability in right-handed female adults, while the direction of the correlation was reversed for right-handed males. When the data from males and females were analyzed together, they showed a quadratic relationship between testosterone level and spatial ability. On this basis, the authors argued that testosterone influences spatial ability in a nonlinear fashion.

If testosterone is linked to DD rates in a nonlinear way, it follows that the observed relationship between these variables depends on the sample, and that sample differences could produce the inconsistencies reported in previous studies. That is, a recruitment of samples with low versus high testosterone levels could lead to drastically different results. Likewise, exogenous administration of testosterone could influence DD rates differentially, depending on individual differences in baseline testosterone levels. In a highly diverse population, any effects of testosterone administration might be obscured when the participant data are analyzed at the group level.

In order to ascertain whether there is a nonlinear relationship between testosterone and DD, data from individuals with a wide range of testosterone levels should be collected. One way to achieve this is to examine sex differences in the relationship between testosterone levels and DD rate (Gouchie and Kimura, 1991; Moffat and Hampson, 1996). If a nonlinear relationship exists as described above, differential patterns of relation between testosterone levels and DD rates will emerge in males and females, as the latter group has markedly lower baseline testosterone levels (Stanton, 2011; Dabbs, 1990). A field of research closely focused on this point concerns sex differences in DD. Bayless et al. (2013) reported that male rats choose immediate rewards over delayed larger rewards more frequently than females. In humans, some studies report larger DD rates in females (Reynolds et al., 2006; Beck and Triplett, 2009), while others report the opposite sex difference (Peper et al., 2013; Shibata, 2013). Still others have failed to find any sex differences related to DD (Cross et al., 2011; Lucas and Koff, 2010; de Wit et al., 2007). Aside from group-level sex differences, the link between baseline testosterone levels and inter-temporal choice has been largely ignored, especially in females. One notable exception is Lucas and Koff (2010), who reported a negative correlation between DD and the 2d:4d digit ratio, which is known to be a stable measure of prenatal exposure level to androgen, in adult females. Their results seem to indicate that the organizational effect (Dorner, 1983; Phoenix, 2009) of fetal testosterone serves as one determinant of DD in females. Interestingly, no such phenomenon was observed in males, giving partial support to our hypothesis that sex differences exist in the relationship between androgen exposure level and DD rate. However, few studies have addressed the link between DD and the currently circulating levels of bioactive testosterone. Thus, whether DD is susceptive to the activational effect (Dorner, 1983; Rubinow and Schmidt, 1996) of testosterone in females is unclear.

In the present study, we investigated sex differences in the relationship between baseline testosterone levels and DD rates in healthy adult males and females. We used salivary testosterone concentrations because this measure has been shown to specifically reflect level of bioactive testosterone including free and weakly-bound fraction of testosterone (Papacosta and Nassis, 2011). We also analyzed the relationship between testosterone levels and probability-discounting (PD) rates. PD refers to the tendency for people to discount the utility of rewards according to the probability of gaining those rewards (Rachlin et al., 1991). For example, the subjective value of a 1000 dollar reward that can be obtained with a probability of 90% is estimated to be less, or discounted, compared with a certain reward of 1000 dollars. The degree of discounting becomes larger as the probability to obtain that reward gets smaller. Individuals with higher PD rates tend to discount the utility of a reward more steeply as the probability of gaining that reward gets smaller. In a typical experiment of PD, participants are required to choose either smaller certain reward or larger uncertain reward. In contrast to the DD task, the risk associated with each alternative is explicitly stated in the PD task. Although some authors argue that people view the temporal delay as a form of risk or uncertainty in the DD task (Mazur, 1995; Rachlin et al., 1991), PD is thought to reflect the level of risk tolerance/preference more directly than DD; risk-prone individuals are more likely to choose a larger uncertain reward over a small certain reward compared with less risk-tolerant individuals (Madden et al., 2009). Although controversial (Yi and Landes, 2012), PD is supposed to have certain predictive power outside-laboratory. For example, Madden et al. (2009) have shown lower PD rates in pathological gamblers than in controls.

Despite the structural similarities, normal participants usually show qualitative differences in their behavioral responses to these two tasks. For example, larger rewards typically decrease DD rates (Kirby and Maraković, 1996) while increasing PD rates (Myerson et al., 2011). Consistently, neuroimaging studies have revealed that DD and PD tasks