Testosterone and unconscious positive priming increase human motivation separately

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Clinical observations suggest that testosterone generates unconscious broad-spectrum motivations to act. It has also been suggested that subliminal positive-priming techniques also unconsciously enhances motivation for action. This placebo-controlled study examined the separate and possible joint contributions of these assumed unconscious sources of human motivation. Healthy females were administered 0.5 mg sublingual testosterone or placebo. Next, they were subliminally primed with action concepts that were paired with positive or neutral cues, and indicated their motivation for the respective action. Testosterone and positive priming both increased the motivation for action, but there was no joint contribution. Possibly, testosterone pushed the motivational brain system to a limit allowing no add-on contribution by priming, but our data also agree with neuroimaging evidence showing that the neural (subcortical and cortical) pathways of motivation can be functionally disconnected by testosterone administration. *NeuroReport* 20:1300–1303 © 2009 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Introduction

The steroid hormone, testosterone, is associated with social dominance, competition, and sexual motivation in animals and humans [1,2]. However, the hormone may also act more generally on motivation. Studies with hypogonadal (low testosterone) patients suggest that testosterone deprivation results in apathy and lack of motivation [3–5]. Furthermore, psychobiological research in animals suggests that increasing levels of testosterone modulate the working of brain structures involved in motivation and emotion [6,7]. For instance, injection of testosterone in the nucleus accumbens motivates animals to engage in actions that are usually determined by external rewards. The hormone thus seems to enhance motivation without external reward priming. Testosterone's critical sites of action in animals on motivation and emotion are the subcortical regions of the brain [8,9]. The hormone's effects on human motivation are therefore likely to be produced bottom-up. The role of testosterone in general motivation in humans has not yet been investigated in fundamental research, and surely not in a causal fashion. Nonetheless, effects on fear motivation suggest that testosterone may enhance the general motivation to engage in behavior in an unconscious fashion [10]. That is, testosterone may serve as an unconscious source of human motivation.

Interestingly, another recently discovered unconscious source of human motivation concerns the acquired reward value of behavior. Specifically, research shows that humans become more strongly motivated to engage in everyday behaviors (e.g. solving puzzles, drinking water) when the cognitive representation of that behavior is activated outside of awareness, that is, subliminal priming, and that representation has been paired with (rewarding) positive cues [11–13]. For instance, in one study human participants were subliminally primed with words representing the act of drinking water on a computer screen, and these action-concept primes were either followed by briefly presented, though consciously visible positive words (e.g. such as nice or pleasant) or not. Results showed that pairing the representation of drinking water with positive words augmented the motivation to drink water, as was revealed by subjective reports on motivational strength of drinking and overt drinking behavior. Although the neurological basis is not yet fully delineated, these unconscious positive priming effects are supposed to unfold in a two-step manner. First, the subliminal action-concept primes and the consecutive perception of positive stimulus words target cortical areas relevant for action preparation and semantic processing. Subsequently, the affective tag attached to the action-concept evokes the subcortical motivation system, thereby more strongly motivating the person to engage in the specific behavior.

Animal and human research suggests that testosterone motivates human behavior unconsciously without additional reward priming of behavior, but effects of testosterone on motivation in general have never been

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examined in a controlled manner. Furthermore, priming the representation of behavior together with positive reward cues may enhance people's motivation to engage in the behavior unconsciously. However, the joint contribution of these distinctive two sources of human motivation, that is, a hormonal manipulation targeting subcortical areas versus a cognitive manipulation targeting cortical areas that influence subcortical regions in a top-down fashion, has yet to be identified. Here we used a placebo-controlled design to, first, examine whether testosterone and positive affect attached to the representation of behavior increase human motivation unconsciously. Second, we looked for a joint contribution of these potential unconscious sources of motivation. Examining this joint contribution promotes a better understanding of the neural processes by which the hormone testosterone and subliminal positive priming of action-concepts produce motivation to engage in behavior in the absence of awareness.

Methods

Twenty-four healthy young women (mean age = 20.2 years) were randomly (and blind to experimenter) assigned to the testosterone or placebo condition. Informed consent was given in written format. The protocol was approved by the Medical Ethics Committee of the Utrecht University Hospital. We eliminated influences of hormonal change due to menstrual cycle by recruiting only women who took single-phase oral contraceptives while testing them during the 'pill-taking period', wherein the menstrual cycle is virtually absent. None of them smoked and used medication other than oral contraceptives. The drug sample consisted of 0.5 mg of testosterone, 5 mg of cyclodextrine (the carrier), 5 mg of ethanol, and 5 ml of water. Testosterone was omitted from the placebo sample, and both testosterone and placebo were administered sublingually. Based on a decade of research using this method we followed a 4-h delay between testosterone administration and task performance [2,14].

Four hours after the administration of the drug, participants performed a computerized task to attach (sex-unrelated) behaviors to positive affect. The task and stimulus materials [10 everyday behaviors (e.g. doing puzzles), five positive words (e.g. nice) and five neutral adverbs (e.g. such)] were taken from previous research [12]. Participants indicated whether they wanted to engage in each behavior (11-point scale) presented on the computer screen (100 Hz). Before participants indicated their motivation to engage in the behavior within a trial, words were presented on the screen, and participants had to count dots that could appear above or below these words. There were five neutral and five positive trials.

In neutral trials, an action-word was followed by five neutral words, whereas a nonword (e.g. devulsaw) was followed by five positive words. In positive trials, the action-word was followed by positive words, and a nonword by neutral words. Within each trial, the 10 pairings were presented in random order, as was the order of the trials. Furthermore, for each participant five action-words were randomly assigned to the neutral condition and the other five to the positive condition. Note that in each condition participants were exposed to neutral and positive words. The only difference was that an action-concept was either directly paired to positive affect (positive trials), or not directly linked to positive affect (neutral trials). Each pairing in a trial started with a fixation cross presented on the screen for 500 ms, followed by a random letter string presented for 150 ms (premask). Next, an action-word or a nonword was presented subliminally (30 ms) followed by a random letter string (postmask, 150 ms; see Ref. [11] for a subliminality check). Finally, a neutral or positive word appeared on the screen for 150 ms (consciously visible), which was presented with a dot or not. After 10 of these pairings, participants indicated their motivation to engage in the subliminally primed action-concept, and then reported the number of dots they have seen. After 2000 ms, a new trial started.

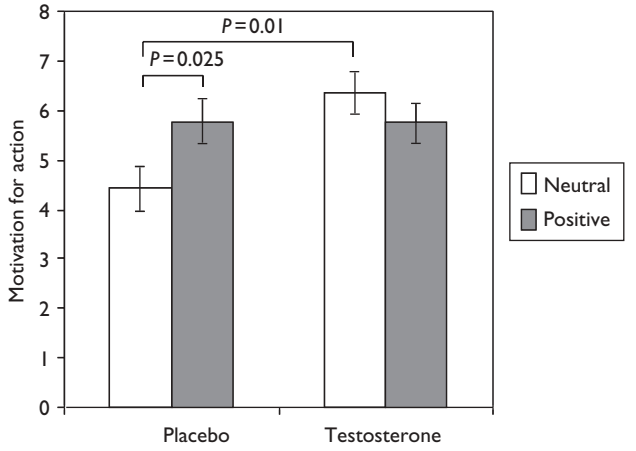
At the end of the session, the Profile of Mood States with subscales anger, anxiety, fatigue, vigor, and depression [15] was administered to control secondary mood-generated effects of testosterone on motivation. Finally, participants were debriefed and questioned about the experiment. Debriefing showed that none of them indicated awareness of the aim of the study. They received a fee for participation. Owing to a technical error, data of two participants were lost.

Results

Effects on motivation for action

Data were analyzed using nonparametric statistics. Wilcoxon-rank test showed that after placebo administration, positive-relative-to-neutral priming resulted in a significant rise in motivation, $z(1,22) = -2.25$; $P = 0.025$. However, positive-relative-to-neutral priming had no influence after testosterone administration, $z(1,22) = 0.97$; P value not significant. To obtain further insights, we subtracted neutral priming from positive priming scores to create a variable positive-prime-effect. An independent Mann–Whitney over this positive-prime-effect showed a significant testosterone treatment interaction, $z(1,22) = -2.46$; $P = 0.01$, driven by a significant effect of testosterone treatment after neutral priming, $z(1,22) = -2.54$; $P = 0.01$, while nothing happened after positive priming, $z(1,22) = 0.1$; P value not significant. Figure 1 shows that positive priming worked, and that testosterone substantially increased motivation after neutral priming, but a joint contribution of testosterone and priming was absent.

Fig. 1



Motivation to engage in behavior as a function of the testosterone treatment (placebo vs. testosterone) and priming (neutral vs. positive). Only significant differences are marked. Error bars represent the standard error.

Effects on mood states

We also analyzed effects of the testosterone treatment on the subscales anger, anxiety, fatigue, vigor, and depression as assessed by the Profile of Mood. However, these analyses revealed no significant effects on any of the five scales (all P values > 0.35). The absence of a mood effect indicates that the effects of testosterone on enhanced motivation to engage in behavior cannot be attributed to secondary mood-generated effects of the hormone.

Discussion

The goal of this study was to investigate the effects of testosterone and subliminal positive priming of action-concepts on human motivation to engage in the primed action-concepts without awareness of the source of these effects. First, our data show that a single administration of testosterone enhances the motivation to engage in the primed action-concepts, whereas previous study on humans suggests that low levels of testosterone are associated with apathy and lack of motivation [2–5]. Here we demonstrate for the first time that testosterone causally increases our general motivation to engage in behavior. In doing so, this study provides new evidence for the notion that treatment with the hormone testosterone modulates the working of subcortical networks involved in reward processing and motivation, thereby augmenting people's motivation to engage in action without any confounding influences of awareness [16].

Furthermore, the present findings indicate that positive priming of action-concepts unconsciously increases the motivation to engage in the action in general. Specifically, subliminal priming of an action-concept caused participants to become more motivated to engage in action, but only when the primed action-concept was directly followed by a positive rewarding word-cue. Importantly, this unconscious subliming positive priming effects emerged only when the level of testosterone was not increased (in the placebo condition). These findings replicate and extend previous research [11,12] wherein it was shown that subliminal positive priming effects occur independent of any additional e.g. hormonal manipulations. The question remains how this separate contribution of testosterone and subliminal positive priming of action-concepts as nonconscious sources of human motivation may have occurred.

The psychobiological mechanisms by which, in the absence of a joint contribution, different implicit causes as hormonal manipulation and subliminal positive priming of action-concepts can lead to similar motivational effects on behavior is not easily explained. As noted earlier, however, testosterone's effects on motivation are predominantly generated by the subcortical circuits [8,9]. One important structure targeted by testosterone is the amygdala, which with its rich connections to prefrontal regions, such as the orbitofrontal cortex is vital in the bottom-up regulation of motivation. In our subliminal positive priming, participants attended the subliminally presented action-concept primes and consecutively processed positive affective word cues. In this priming procedure there is, given higher-order linguistic concepts involved, initially a role for the cortical structures, and the subcortical circuits become involved in a top-down fashion. Evidence suggests that orbitofrontal and medial structures of the prefrontal cortex process subliminally presented information, and the orbitofrontal and medial structures of the prefrontal cortex are densely connected with the amygdala, and other reward-related structures in the brain [17].

Our data also concur with animal research discussed above, which shows that testosterone enhances motivation without external reward priming. However, external positive priming worked here, but did not add motivation after testosterone administration. The separate contribution of testosterone and positive priming might suggest that the subcortical and cortical inputs to the motivational systems have become functionally disconnected. Indeed, human neuroimaging data indicate that testosterone functionally decouples subcortical from cortical structures [2,18], and this could presently have precluded the joint contribution with subliminal positive priming.

However, it might also be argued that a ceiling, or limit in motivation for action was reached after testosterone administration, allowing no add-on effects of positive

priming. This limit is unlikely a property of our measurement scale, as there was much room for improvement on the scale (the mean motivation score in the testosterone and neutral priming condition was around 6.4 on an 11-point scale). The brain, however, might adaptively use a limit when motivation is sufficient for an action to be performed, to not needlessly use its processing resources [19].

Nonetheless, as noted above causal data involving testosterone administration in human indicate that testosterone holds properties to disconnect subcortical and cortical inputs to the motivational systems, which might also explain the lack of synergism in the effects of testosterone and priming [2,18]. If so, increased levels of testosterone may enhance motivation for action without much intervention of cortical areas, even though these areas process information highly relevant for the behavior at hand.

Conclusion

We pitted the effects of testosterone administration and subliminal positive priming against each other on the strength of human motivation to engage in behavior, and we found that testosterone enhances motivation without subliminal positive priming. However, subliminal positive priming increased motivation for action as well, but did not further add to the motivational strength after testosterone administration. Testosterone may have boosted the motivational system to a limit or disconnected subcortical and cortical pathways of motivation.

Acknowledgements

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