Link between mental health and self-reported number of digital hairs suggests new way to measure expressed testosterone

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Abstract

There is growing consensus that testosterone is related to mental and physical health, but the underlying mechanisms are still poorly understood. One explanation for the conflicting results found in the study of testosterone is that this hormone is needed for the arousal that signals the expectation of a positive outcome, meaning that high testosterone can be expected to lead to impulsive behavior and thus enhance a person's risk to develop an anxiety disorder, whereas low testosterone would lead for instance to apathy and thus enhance a person's risk to develop a mood disorder. To investigate this hypothesis I explored the relation between emotionality, mental health and the self-reported number of digital hairs as an indicator of expressed testosterone in an online survey in which 316 Dutch (speaking) men and women participated. Using factor analysis on a pool of items probing the participant's tendency to react emotionally I identified four types of emotionality: an internalized negative type, a positive type, a sexual type and an externalized negative type. I found that mental health was indeed higher at intermediate levels of digital hair, and that there was a positive association between general emotionality and digital hair, though only in partnered persons and women. These results should be interpreted with caution because data were collected during the COVID-19 pandemic and with the exception of partnered men all participants had relatively low scores on the used measure for mental health. Nevertheless, the fact that by using the digital hair measure a distinct pattern was found suggests that this measure may be employed as an easy to use and non-invasive marker for expressed testosterone, although the measure is probably more reliable if the assessment is done by a trained assessor, especially in men as they have more digital hair then women. To further elucidate the association between testosterone and reward related arousal I introduce the concept of reiteration as the phenomenon that links perception, representation and behavior.

Key words: digital hair, testosterone, arousal, reward, mental health, reiteration

1 Introduction

Although there is growing consensus that testosterone (T) deficiency related to aging can impair mood and sexual function, the mechanisms underlying these effects are still poorly understood, which may be one of the reasons why adequate treatment is not always sought and/or received (Davis et al., 2019; Scavello, Maseroli, Di Stasi, & Vignozzi, 2019; Walther, Breidenstein, & Miller, 2019). In this context one possibility worth exploring is the relation between T and autonomic arousal, i.e. the response of the sympathetic nervous system that gives emotions their intensity (Chu, Gagnidze, Pfaff, & Ågmo, 2015). The phenomenon of arousal may explain how it is possible that T has been found to have both positive and negative effects on mood (e.g. Johnson, Nachtigall, & Stern, 2013) and especially anxiety (Celec, Ostatníková, & Hodosy, 2015; Stanikova et al., 2019). Firstly, there is a wealth of evidence that T is involved in a range of emotions (Bos, Panksepp, Bluthé, & van Honk, 2012; Klein et al., 2019), arousal is an important factor in emotion (e.g. Calderon, Kilinc, Maritan, Banavar & Pfaff, 2016; Kreibig, 2015), and it has been linked to T. Secondly, androgens have been linked to mental health in different ways involving arousal. In people who abuse synthetic androgens for instance, they are thought to reduce emotional regulation by lowering the threshold for arousal, resulting in an increase in emotional reactivity, motor response, and alertness to sensory stimuli that translates into the impulsivity, aggression and anxiety seen in this group of people (Hildebrandt, Heywood, Wesley, & Schulz, 2018; Oberlander & Henderson, 2012). Alternatively, depression has been associated with both low arousal (Benning & Ait Oumeziane, 2017) and low T (McHenry, Carrier, Hull, & Kabbaj, 2014). This finding is seemingly hard to reconcile with the finding that depression is also highly associated with anxiety (Fava et al., 2000), as this is characterized by high arousal. However, the arousal seen in anxious people appears to be of a particular type, as under everyday stress they tend to react with less physiological flexibility than others (Hoehn-Saric & McLeod, 2000). Taken together these findings suggest that the association between T and a particular type of emotionality can reflect a direct effect, namely when it enhances emotions through its effect on arousal, but it need not be. As the example of anxiety shows, at lower levels of T the relation may well be negative, which suggests there are at least two types of arousal related to emotion and T may only be involved in one. To be clear, in the case of other types of emotionality the relation with T may be linear or asymptotic. For instance, given the fact that supplementation of T can improve sexual function in hypogonadal men and women one would expect a positive relation at the lower levels of T on sexual arousability (Davis et al., 2019; Walther, Breidenstein, & Miller, 2019), but at higher levels there may be no association at all (Goldey & Sanders, 2012; Raisanen, Chadwick, Michalak, & van Anders, 2018).

To summarize, in the study of T we should be careful not to assume that an effect seen at lower levels of T will exist at higher levels as well. Furthermore, a relation between T and an emotion may be direct, meaning that higher T-dependent arousal leads to more emotion, but at least in the case of anxiety it may be indirect as well, meaning that there is no relation or a negative relation between T and anxiety when this emotion is associated with depression.

Studies that investigate the behavioral effects of endogenous T are complicated by the great individual differences in the sensitivity to the hormone. A possible solution for this problem may be the use of middle-phalangeal hair (MPH), i.e. the number of hairs a person has on the middle phalanxes of their fingers, as a marker of (expressed) T. Arguments for this can be found in Westlund, Oinonen, Mazmanian & Bird (2015). For instance, not all people have the genetic predisposition for MPH, but when MPH is present it is most likely to be found on the fourth digit, while the second digit is the least likely to have MPH. This suggests a link to testosterone because the relative lengths of the second and fourth digits (2D:4D) is thought to correlate negatively with prenatal testosterone and positively with prenatal estrogen (e.g. Manning, 2011). No studies linking MPH to hormone levels have been done in women, but positive associations between MPH and androgens have been found in men. Lastly, MPH has been linked to the physical side-effects of hormonal contraception in women that are attributed to the decline in androgens seen in women who use this type of birth control (Oinonen, 2009). According to Westlund et al. (2015) 30% of the population of European descent do not have the genetic predisposition to grow MPH. This means the measure is not suitable for assessing the effects of T in people with low levels of the hormone, which is problematic in the case of curvilinear effects. It also means the measure cannot be used in the diagnosis of low T in patients, although it may be used in the development and validation of questionnaires that can help diagnose this condition in women as well as in men. This would be welcome, as to my knowledge the questionnaires that are available at the moment are all directed at men. In conclusion, if in at least some people MPH is indeed a marker for expressed T that can be measured reliably through self-report, then it may be possible to study the behavioral effects of T through (online) surveys so that for instance new diagnostic tools can be developed. In the present study I therefore used an online survey to explore the relation between a person’s tendency to become aroused in emotional settings, that is their emotionality, their mental health and their level of expressed T as indicated by their MPH.

Testosterone, arousal and emotionality

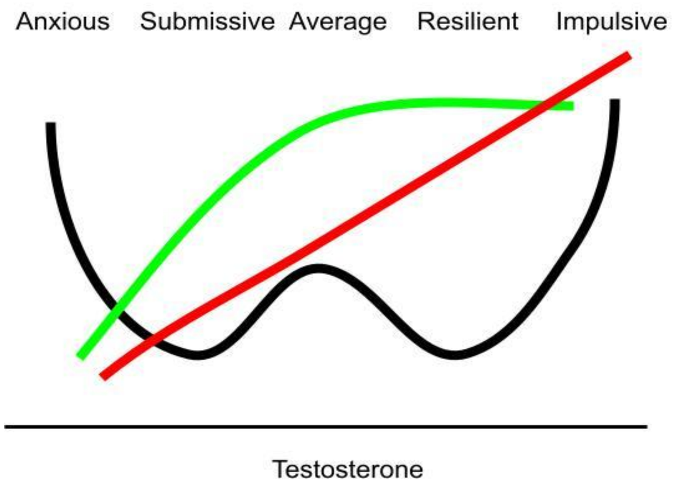
Testosterone has long been associated with the related phenomena reward, approach and motivation. For instance, a single administration of testosterone enhanced women’s readiness to engage in subliminally primed activities as much as subliminally presented rewards did, leading the authors to the conclusion that testosterone modulates the working of the brain circuits involved in reward processing and motivation outside of awareness (Aarts & Van Honk, 2009). Rats that were treated with testosterone chose to wait 45 seconds to get a bigger food reward more frequently than vehicle-treated rats, suggesting that T predicts sensitivity to reward rather than impulsivity (Wood et al., 2013). In at least one fMRI study exogenous T was associated with both liking and wanting (Hermans et al., 2010). T acts on central dopamine pathways, so the evidence that dopamine is related to reward makes it plausible that testosterone is too (Campbell et al., 2010; Jardi et al., 2018; Sinclair, Purves-Tyson, Allen, & Weickert, 2014). Lastly, the observation that T makes stimuli that are related to the goals or concerns of the individual more salient, can be explained by the fact T enhances the reactivity of the amygdala to emotional stimuli (Bos, van Honk, Ramsey, Stein, & Hermans, 2013; Van Wingen et al., 2009). In conclusion, if there are indeed two types of arousal, one would expect the one that is dependent on T to be related to reward.

Although emotions are commonly thought to require cognitive processing so that relevant aspects of the situation are recognized as relating to the individual's concerns (e.g. Frijda, 1986), to my knowledge there is only one neuroscientific theory of emotion that offers a relatively worked out account of how emotion and cognition are related, namely the predictive processing approach (Gross & Barrett, 2011; Barrett & Satpute, 2019). In this upcoming paradigm, that is as much computational as neuroscientific, the individual is thought to continuously update a generative world model, i.e. a model of the world that specifies outside of awareness what the individual is likely to feel and do given the things they have experienced so far. To give an example that relates to this study, if a person expects to feel sexual arousal in reaction to seeing their partner, but as a result of low T this arousal does not occur, the initial conclusion that their partner is attractive will not enter awareness, or if it already has, it will now be questioned. Therefore I took as the starting point for this study the assumption that T is needed for the arousal that signals the individual that the thing they are (unconsciously) expecting to do or feel next will be rewarding, i.e. worth the metabolic cost and/or risk.

When we assume that T is needed for this reward signal, it becomes clear that T can help people to behave in an adaptive way, as long as it does not get too high. For instance, if T is relatively high, the individual will get a strong signal to act when this action is likely to be rewarding given the circumstances. As a result, they will intuit what to do, and what not to, especially in social situations, potentially making them more dominant and successful (cf. Eisenegger, Haushofer, & Fehr, 2011). Moreover, as T is also related to physical strength and energy, people with high levels of this hormone will be able to take on more. If T is too high, however, this strong signal will also occur when an action would only be rewarding if the circumstances were different, resulting in maladaptive behavior. If T is too low, the signal that an expected action or emotion is going to be rewarding will not occur at all and the individual may never be really excited or sure about anything. This may be especially upsetting if the low level of T is the result of aging, as in that case the individual was used to getting sufficiently clear signals. Though this may lead to negative emotions, in this case the arousal cannot be T-dependent. Alternatively, if T has always been relatively low, a person may be happy to follow the lead of others, making them submissive rather than dominant (cf. Van Honk, Bos, & Terburg, 2014). And lastly, if T is neither high nor low, a person will be less happy to be a follower, but they may not have the confidence, success and energy of a leader either, as in them the signal that something is going to be rewarding will be weaker than in the people with a relatively high level of T, which may lead to moderately high levels of frustration and anxiety. To summarize, the hypothesis that there is a T-dependent type of arousal related to reward predicts a curvilinear association between T and mental health, distinguishing between an anxious, a submissive, an average, a resilient and an impulsive type (see Figure 1). Interestingly, a similar typology was found in a study using a clustering technique to identify Big Five profiles in four large data sets (Gerlach, Farb, Revelle, & Amaral, 2018). In this study a distinction was made between a reserved type, an average type, the role model and a self-centered type.

Figure 1

Hypothesized relations between testosterone and arousal



Note. The red line represents T-dependent arousal, the black line represents anxiety and the green line represents sexual arousal.

Naturally, in the behavioral sciences quartic associations are unlikely to be found, but one would expect U-shaped associations, reflecting that negative emotionality and thus mental disorders are more likely to be high at the extreme levels of T, or that mental health is more likely to be low at extreme levels of T. The relation between T and sexual emotionality is likely to be similar to the relation between T and sexual arousability I discussed above, i.e. positive, though maybe only at lower to intermediate levels. To my knowledge, the association between the tendency to become physically aroused and the tendency to experience positive emotions is not well- researched, meaning that it is hard to say what relation between T and positive emotionality is the most plausible. One might expect this relation to be positive, but it may also be curvilinear, as people who are anxious as a result of high T may be less likely to interpret situations as positive. Lastly, one would expect a measure of general emotionality to be positively related to T, as in such a measure all types of emotionality would be combined (see Figure 1).

Present study

In the present study I wanted to explore the possibility that T is associated with different types of emotionality in different ways because it is needed for arousal related to reward. To that end I developed a first version of a questionnaire that could assess different types of emotionality. The measures of emotional reactivity that have been developed so far do not seem to assess positive emotionality, let alone sexual emotionality (e.g. Coren & Mah, 1993; Nock, Wedig, Holmberg, & Hooley, 2008). Alternatively, in questionnaires that have scales for positive emotions respondents typically indicate how frequently within a given time frame they experienced a particular emotion, but not how likely they were to react with a particular emotion in a given situation, let alone how likely they were to become aroused generally (e.g. Watson, Clark, & Tellegen, 1988). Additionally, I used self-reported MPH as a marker for expressed T to test the association between T and two validated outcome variables, namely mental health as measured by the Mental Health Inventory (MHI-5; see below) and the Arousal Predisposition Scale (APS; Coren, 1988; Coren & Mah, 1993), and two of the developed emotionality scales, namely internalized negative emotionality and mean emotionality.

2 Method

Participants

In this study, which was approved by the ethical committee of the Utrecht University, 169 women (age range 18-77, *M* = 28, *SD* = 12), 141 men (age range 18-73, *M* = 47, *SD* =17) and six other Dutch (speaking) participants completed the survey after having provided informed consent. Participants were either students, most of whom received study credits for their collaboration, or recruited through social media, in which case they could win a voucher for 10 Euros. Data were collected over two months, starting two weeks before the most severe COVID-19 measures were lifted and 13% of both male and female participants indicated they had had signs of COVID-19 the month before participating. Of the women 50% used hormonal contraception. Antidepressants were used by 3% of both men and women. Participants had an average score of 67 (men) and 60 (women) on the MHI-5. Twelve participants who indicated they reported a mental disorder and/or had an extremely low score (<21) on the MHI-5 were included in analyses using only physical measures but excluded from the main analyses. This resulted in a sample of 304 participants with a mean MHI-5 score of 66. In this sample 50% of the men indicated they had MPH, and 40% indicated they had not. Of the women 40% indicated they had MPH, and 57% indicated they had not. In men with MPH the mean number of hairs was 9.1 (*SD* = 8.6), in women this number was 5.5 (*SD* = 3.7). For completeness, women who had MPH, scored significantly higher on mental health than women who had not (66 vs. 60, p=.04), whereas men who had MPH scored lower on mental health, though not significantly so, than the men who had not (68 vs. 72, p=.24). In the participants who had MPH but were excluded because of mental health problems MPH was relatively high (*M*=12.5 in men and *M*=7.3 in women).

Measures

The online survey used in this study was made in Qualtrics and could be completed in about 20 minutes. The items were in Dutch and participants were instructed to skip any item that they could not or did not want to react to. The sliding scale used in many of the questions was typically set to transform the participants' answers into a scale ranging from 1 to 10, with an accuracy of two decimals.

To assess *emotionality* I made a pool of 67 items thought to cover the domains positive emotionality (happiness and connectedness), negative emotionality (anger, anxiety and sadness), sexual emotionality and general emotionality. Some items were already tested in a pilot study, but most were new. Additionally, items were constructed so they could be answered by almost everyone, meaning they were not about infrequent situations and it was not assumed for instance that respondents had colleagues or partners. Importantly, items were meant to probe inclinations and feelings, rather than behaviors. The focus in this study was on the individual's tendency to become aroused in emotional settings rather than on their actual behavior or experience, as people may regulate their behavior and there may be periods in their lives in which some emotions are more likely to occur than others. Examples are *The smallest things could make me happy, At times I felt great love for one or more people I was around, Anger I could feel physically, I worried about what others thought of me, Whenever I felt sad, this feeling stayed with me for a long time, I got aroused while watching sex scenes in movies* and *Music made me emotional.* Respondents were asked to indicate on a sliding scale to what extent these statements applied to them in the previous year. If they felt that this was not possible because within the last weeks or months things had changed, then they were asked to answer the question with respect to those last weeks or months. The terms were presented in a random order, with the exception of the item probing sexual emotionality, which were grouped and presented in a fixed order.

In order to assess the validity of the emotionality measures I included the *Arousal Predisposition Scale* (APS; Coren, 1988; Coren & Mah, 1993). This inventory consists of 12 items to be responded to in a five-point Likert scale ranging from *never* to *always* and was developed to study insomnia. It was validated using physiological measures (Coren & Mah, 1993) and appears to have good psychometric properties (Ruivo Marques, Gomes, & de Azevedo, 2018), but to my knowledge it is not widely used. For this study I translated the items and used a sliding scale.

As a measure of *mental health* I used the MHI-5. This inventory consists of the following questions. *Over the last four weeks, how often have you been a very nervous person? How often have you felt so down in the dumps that nothing could cheer you up? How often have you felt calm and peaceful? How often have you felt downhearted and blue? How often have you been a happy person?* Each item has six possible responses ranging from *all the time* to *none of the time*. The third and the fifth question are reverse scored, total scores range from 0 to 100 and scores below 71 are considered an indication for poor mental health (Hoeymans, Garssen, Westert, & Verhaak, 2004; Van den Beukel et al., 2012). For this study I used the translation that is used by Dutch public health institutions (Driessen, 2011), employing a sliding scale ranging from *none of the time* to *all of the time*. Additionally, I made one new variable, namely *depression*, by averaging the scores on the second and fourth items, and another one, *anxiety*, by averaging the scores on the first and third items.

To assess *MPH* an item was included asking the participant to count the numbers of hairs they had on the middle phalanx of the fourth digit of the hand they did not use for writing. A photograph was added for clarification. Through an oversight the first 121 participants were not asked to give the exact number of hairs, but only to indicate whether they had 0, 1-3, 4-6, 7-9 or 10 or more hairs. For analysis their scores were substituted by the mean of these categories. Furthermore, participants who reported having no hairs (57%) were excluded from analyses that involved MPH.

To assess the validity of the MPH measure as a marker of expressed T, I included multiple choice items about *hormonal contraception*, (mental and physical) *sexual function* and items with sliding scales about (mental and physical) *fitness*, including *energy*. Examples of the questions relating to sexual function are *Over the last two weeks, how much did you fantasize about sex?* and (if applicable) *In the last six months, how intense was your most intense climax?* Examples of the items relating to energy are *Over the last two weeks, I felt fit* and *I felt tired*.

Analyses

All analyses were done using SPSS, version 26. To find potential confounders I examined age, gender, body mass index (BMI), antidepressant use, mental health, energy, physical condition, reported signs of COVID-19, relationship status and associations between these variables that could play a role in the subsequent analyses. For the regression analyses I performed I used the curve fit method to examine (recti)linear as well as quadratic models whenever other than linear associations could be expected on theoretical grounds. Two-sided p values of less than 0.05 are reported as statistically significant. I did not correct for multiple testing, as this was meant to be an exploratory study and I wanted to avoid type 2 errors.

To uncover the dimensional structure of trait emotionality I performed a Principal Component Analysis using an oblimin rotation with Kaiser Normalization on the 67 items I had developed. From each factor this revealed I took the items that did not load on other factors as well and used these as the starting point of a scale, after which I used Cronbach's alpha to develop these scales further. To explore the relation between the distinguished trait emotionalities I used Pearson's R. To assess the validity of the scale I performed a regression analysis, using the mean score on the APS as a predictor for the mean score on a scale that was comprised of the items with the highest item-total correlations that together were meant to equally cover the four developed subscales and general emotionality (*mean emotionality*).

To assess the validity of MPH as a marker of expressed T by examining its association with age, energy and sexual function I performed linear regressions. To assess the association between MPH and gender I employed an ANOVA and an additional regression between MPH and body length for participants younger than 35 to exclude the possibility that men had more MPH because they had longer digits. To assess the validity of MPH as a marker of expressed T by examining its association with hormonal contraception use, I performed ANOVAs with hormonal contraception as the independent variable and as the dependent variables MPH and variables that were meant to assess the side effects of hormonal contraception, namely energy, sexual function and mental health, in women under 45.

To assess the relation between expressed T on the one hand and emotionality and mental health on the other I used four outcome variables. Two were validated measures, namely the MHI-5 as an indicator of mental health and the APS as a measure of (general) emotionality. The other two were the emotionality scale based on the factor that explained the most variance in the factor analysis and the emotionality scale meant to assess mean emotionality.

3 Results

Potential confounders

Because I a national study showed that indeed during the COVID-19 pandemic mental health was lower than normal all over, but especially in young people, women and singles (Reep & Hupkens, 2021), I examined the participants' scores on the MHI-5 and found the following. Participants had an average score of 62 (women, $SD = 18$) and 68 (men, $SD = 19$) on the MHI-5, whereas from the years 2000 to 2009 these averages ranged from 76 for women to 82 for men (Centraal Bureau voor de Statistiek, 2014). Moreover, there was an interaction between gender and relationship status on mental health ($F(1, 287) = 5.12$, $p = .02$, partial $\eta^2 = .02$), such that men in relationships had a higher mean score on the MHI-5 than the other groups (72 vs. 62 to 64) and this difference was significant for all contrasts ($ps < .001$). For this reason, I standardized the MPH scores for men and women separately, having removed the outliers (values > 2*SD*), so men and women could be analyzed together. The scores on the other outcome variables I standardized for men and women separately without removing the outliers, so they too could be analyzed together. This made it possible to analyze the effect of MPH on the outcome variables for the entire sample and four subgroups, namely men, women, partnered persons and singles.

Types of emotionality

The factor analysis I performed yielded a four-factor solution as the best fit for the data, accounting for 44.8% of the variance. The items that loaded on the first factor, that accounted for 20.3% of the variance, arguably tapped into anxiety and sadness. The scale based on this factor I called *internalized negative emotionality*, as the negativity that characterizes these emotions is turned inward. Example items are: *I got sad over the smallest things. If I got sad, I felt this physically. I got stressed easily. I worried over the smallest things.* The items that loaded on the second factor, that accounted for 13.2% of the variance, seemed to tap into happiness. The scale based on this factor I called *positive emotionality*. Example items are: *Beautiful things made my heart swell. I got excited easily.* The items that loaded on the third factor, that accounted for 6.43% of the variance, were the ones constructed to probe sexual arousability. The scale based on this factor I called *sexual emotionality*. Example items are: *In romantic situations, I got aroused sexually. I got excited when watching sex scenes in movies*. The items that loaded on the fourth factor, that accounted for 4.9% of the variance, were the ones meant to assess anger. The scale based on this factor I called *externalized negative emotionality*, as the negativity that characterizes these emotions is typically directed at other people. Example items are: *If I got angry, I felt this physically. I got furious over small things*. Notably, the items that were meant to probe connectedness or general emotionality loaded on the first and the second factor. The reliability statistics for the developed scales can be found in Table 1. Mean emotionality was significantly associated with the APS ($\beta = 0.70$, $t(287) = 16.55$, $p < .001$). The correlations between the different types of emotionality and the APS can be found in Table 2 for all participants, in Table 3 for men and in Table 4 for women. As can be seen in these tables, all correlations were positive, though not all significantly so.

Table 1

Reliability statistics of the developed emotionality subscales

Type of emotionality	Cronbach's alpha	Number of items	n
Internalized negative emotionality	.93	14	255
Positive emotionality	.87	12	274
Sexual emotionality	.85	9	227
Externalized negative emotionality	.85	7	253
Mean emotionality	.84	15	228

Table 2

Correlations between types of emotionality (n=294)

	Positive emotionality	Sexual emotionality	Externalized negative emotionality	Mean emotionality	Arousal Predisposition Scale
Internalized negative emotionality	.094	.163**	.421**	.810**	.716**
Positive emotionality		.305**	.102	.358**	.225**
Sexual emotionality			.324**	.492**	.254**
Externalized negative emotionality				.567**	.408**
Mean emotionality					.695**

** Correlation is significant at the 0.01 level (2-tailed).

Table 3

Correlations between types of emotionality in men (n=131)

	Positive emotionality	Sexual emotionality	Externalized negative emotionality	Mean emotionality	Arousal Predisposition Scale
Internalized negative emotionality	.114	.429**	.579**	.848**	.688**
Positive emotionality		.357**	.206*	.391**	.240**
Sexual emotionality			.345**	.661**	.407**
Externalized negative emotionality				.638**	.526**
Mean emotionality					.693**

** Correlation is significant at the 0.01 level (2-tailed).

Table 4

Correlations between types of emotionality in women (n=159)

	Positive emotionality	Sexual emotionality	Externalized negative emotionality	Mean emotionality	Arousal Predisposition Scale
Internalized negative emotionality	.030	.268**	.425**	.792**	.686**
Positive emotionality		.381**	.028	.313**	.186*
Sexual emotionality			.265**	.547**	.401**
Externalized negative emotionality				.548**	.407**
Mean emotionality					.684**

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Middle-phalangeal hair

The analyses meant to assess the validity of MPH as a marker of expressed T revealed no association between hormonal contraception and MPH, mental health, energy, sexual function or climax intensity. This means that no conclusion could be drawn about the validity of the MPH measure by comparing it to the effects of hormonal contraception. However, there was a significant association between MPH and BMI (β = -.31, t(113) = -3.44, p = .001), suggesting that MPH is a marker of a physiological factor, though not necessarily T. Men had higher MPH than women, but body length was not related to MPH in men (p = .94), and in women the association was negative (p = .06), indicating that MPH does not depend on digit length. These and other gender differences can be found in Table 5. Notably, in this sample there were no significant differences between men and women in sexual function or fitness, but there were in three of the four types of emotionality.

Table 5

ANOVA results contrasting male and female participants who had middle-phalangeal hair (n=97)

Variable	*M* male	*M* female	*p*	Partial η^2	Scale
MPH	8.6	5.8	.028	.050	n.a.
MHI-5	66.4	63.5	.494	.005	1-100
Mean emotionality	4.8	5.4	.044	.042	1-10
State emotionality	6.9	7.6	.110	.027	1-10
Sexual function	3.8	3.6	.166	.020	1-5
Climax intensity	3.9	4.1	.308	.011	1-5
Energy	3.2	3.1	.869	.000	1-5
Concentration	3.4	2.8	.006	.078	1-5
Total fitness	3.4	3.3	.217	.016	1-5
Internalized negative emotionality	4.1	5.2	.003	.091	1-10
Happy emotionaity	6.0	6.7	.008	.074	1-10
Sexual emotionality	5.5	4.7	.011	.066	1-10
Externalized negative emotionality	4.0	3.7	.460	.006	1-10

As can be seen in Table 6, the regression analyses meant to show the association between MPH and mental health showed the following. MPH was negatively associated with mental health (β = -.24, *t*(114) = -2.71, *p* = .008), but the quadratic test showed that at the lower levels of MPH the association was positive (*p* = .020). Subsequent analyses for men, women, partnered participants and single participants associating MPH with mental health yielded significant results only for women (both *p*s = .03) and partnered participants (both *p*s < .01). For that reason, I restricted further analyses to the entire sample (Table 7), women (Table 8), partnered participants (Table 9 and Figure 2) and partnered women (Figure 3).

Table 6

Relations between MPH and mental health for all, men. women. partnered persons and single persons

	R^2	*F*	*df1*	*df2*	*p*	Constant	*b1*	*b2*
All								
Linear	.059	7.318	1	117	.008	-3.249E-16	-.243	
Quadratic	.065	4.056	2	116	.020	.064	-.188	-.065
Men								
Linear	.044	2.556	1	55	.116	-5.030E-16	-.211	
Quadratic	.045	1.260	2	54	.292	.009	-.198	-.010
Women								
Linear	.074	4.789	1	60	.033	-1.294E-16	-.272	
Quadratic	.117	3.918	2	59	.025	.208	-.186	-.212
Partnered persons								
Linear	.116	8.780	1	67	.004	.159	-.328	
Quadratic	.142	5.466	2	66	.006	.278	-.219	-.115
Single persons								
Linear	.013	.582	1	45	.449	-.206	-.109	
Quadratic	.016	.362	2	44	.698	-.260	-.149	.056

Table 7

Relations between MPH and the main outcome variables

	R^2	*F*	*df1*	*df2*	*p*	Constant	*b1*	*b2*
Mental health								
Linear	.059	7.318	1	117	.008	-3.249E-16	-.243	
Quadratic	.065	4.056	2	116	.020	.064	-.188	-.065
Internalized negative emotionality								
Linear	.021	2.452	1	117	.120	-3.356E-18	.143	
Quadratic	.021	1.257	2	116	.288	-.021	.125	.021
Mean emotion								
Linear	.023	2.716	1	117	.102	1.414E-16	.151	
Quadratic	.023	1.372	2	116	.258	.016	.165	-.017
Arousal Predispositon Scale								
Linear	.043	5.210	1	116	.024	.001	.207	
Quadratic	.043	2.587	2	115	.080	.008	.212	-.007

Table 8

Relations between MPH and the main outcome variables in women

	R^2	*F*	*df1*	*df2*	*p*	Constant	*b1*	*b2*
Mental health								
Linear	.074	4.789	1	60	.033	-1.294E-16	-.272	
Quadratic	.117	3.918	2	59	.025	.208	-.186	-.212
Internalized negative emotionality								
Linear	.033	2.070	1	60	.155	-5.067E-16	.183	
Quadratic	.102	3.352	2	59	.042	-.262	.074	.267
Mean emotion								
Linear	.031	1.932	1	60	.170	2.689E-16	.177	
Quadratic	.053	1.638	2	59	.203	-.146	.116	.149
Arousal Predispositon Scale								
Linear	.044	2.794	1	60	.100	-1.400E-16	.211	
Quadratic	.057	1.782	2	59	.177	-.112	.165	.114

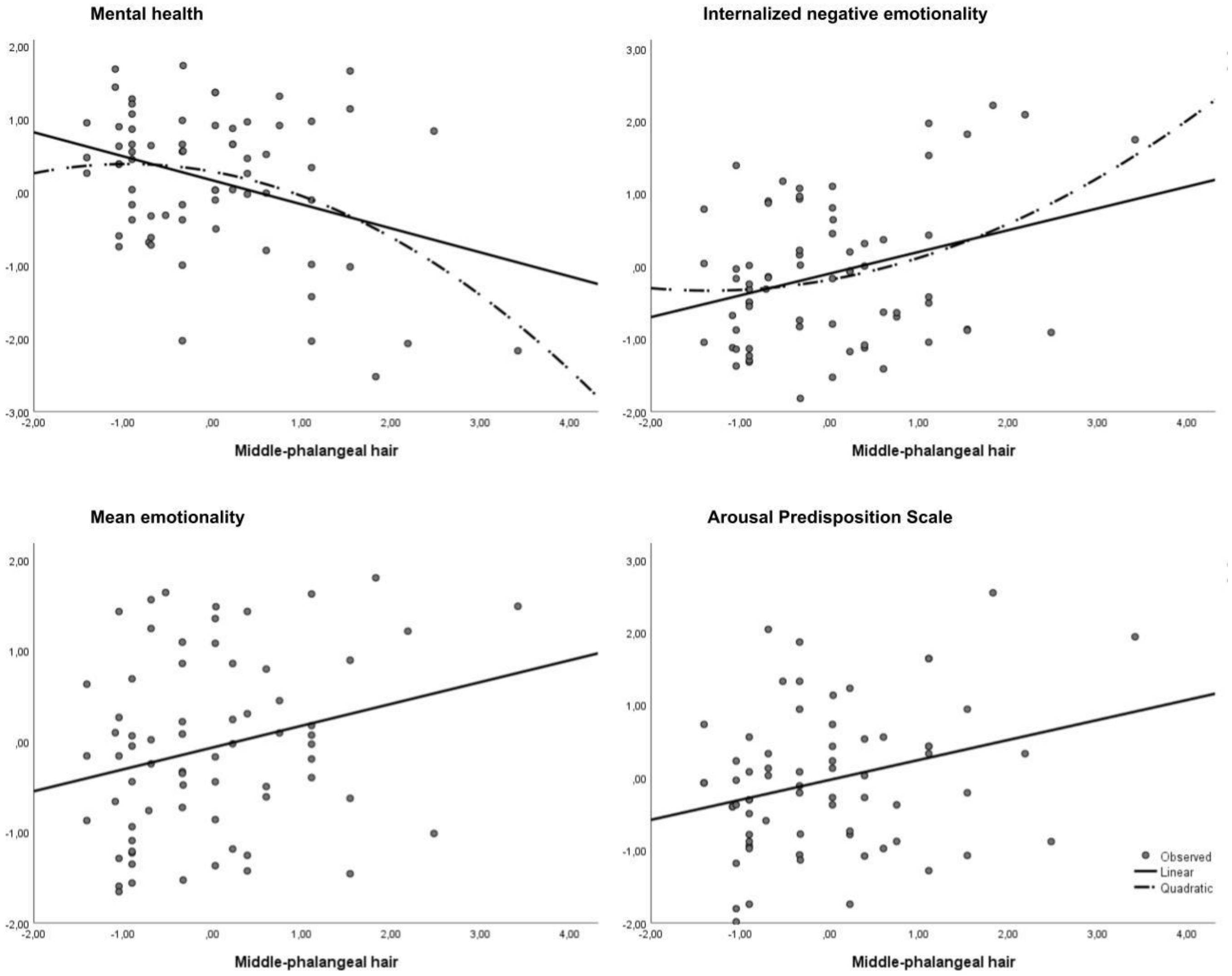
Table 9

Relations between MPH and the main outcome variables in partnered persons

	R^2	*F*	*df1*	*df2*	*p*	Constant	*b1*	*b2*
Mental health								
Linear	.116	8.780	1	67	.004	.159	-.328	
Quadratic	.142	5.466	2	66	.006	.278	-.219	-.115
Internalized negative emotionality								
Linear	.096	7.156	1	67	.009	-.100	.299	
Quadratic	.110	4.071	2	66	.022	-.185	.222	.082
Mean emotion								
Linear	.063	4.489	1	67	.038	-.068	.241	
Quadratic	.063	2.219	2	66	.117	-.079	.231	.011
Arousal Predispositon Scale								
Linear	.082	5.870	1	66	.018	-.030	.275	
Quadratic	.085	3.000	2	65	.057	-.070	.239	.038

Figure 2

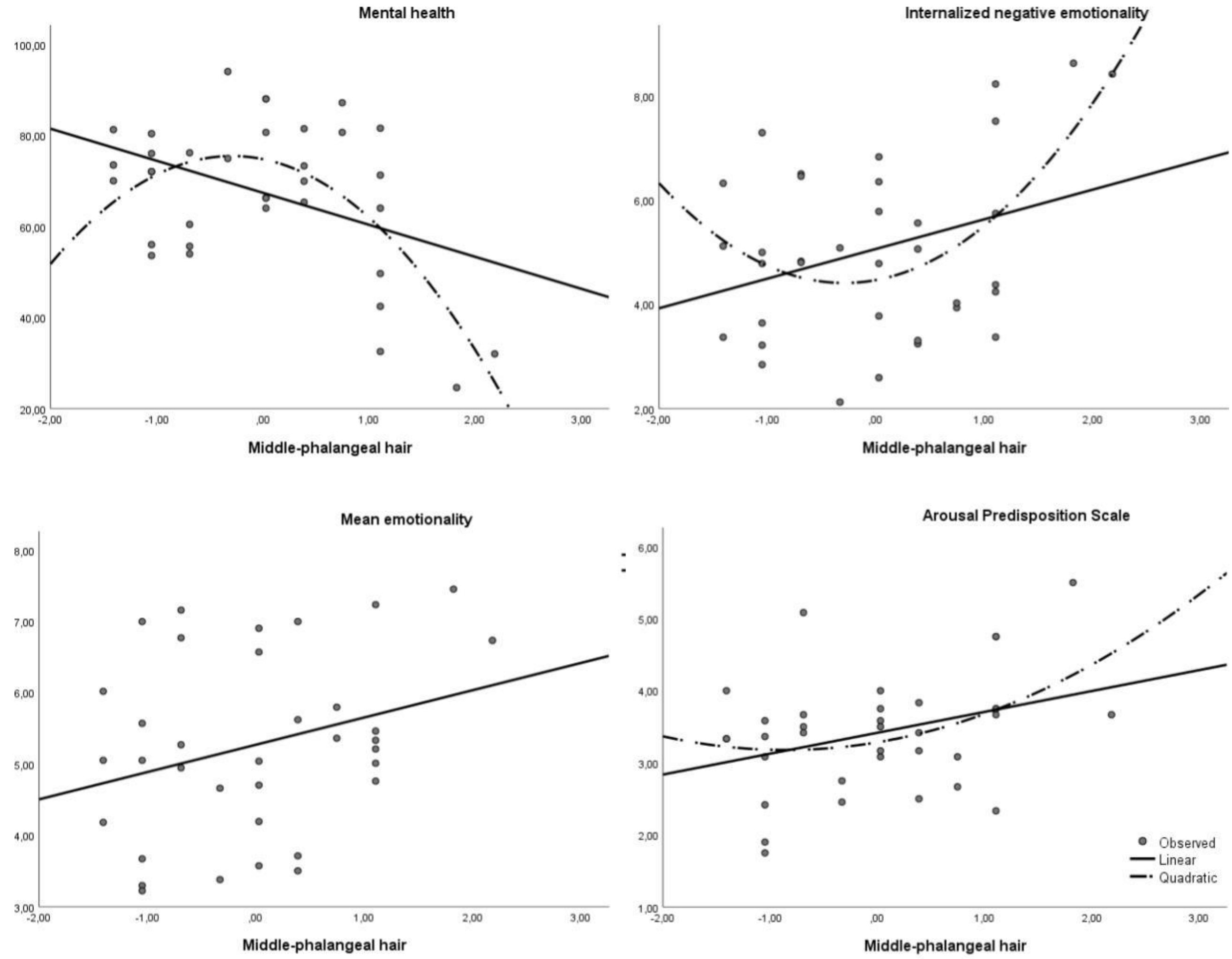
Relations between MPH and the main outcome variables in partnered persons (n=67)



Note. Regression lines are shown for models if *p* <.05.

Figure 3

Relations between MPH and the main outcome measures in partnered women (n=34)



Note. Regression lines are shown for models if *p* <.10.

Given the fact that firstly MPH cannot be used to assess the lowest level of T and secondly the participants with (signs of) a mental disorder or extreme levels of MPH were excluded from analysis, the results visualized in Figures 2 and 3 showed the expected pattern. Overall the association between MPH and mental health was negative (β = -.27 in women (p = .03) and β = -.33 in partnered persons (p < .01)), indicating a negative relation between mental health and T, but at the lowest levels of MPH the trend was positive. Alternatively, for internalized negative emotionality, the associations tended to be negative at the lowest levels of MPH, whereas they were positive over all (β = .18 in women (p = .16) and β = .30 in partnered persons (p < .01)). Lastly, the associations between MPH and the two measures of general emotionality, i.e. mean emotionality and the APS, were linear and in the expected positive direction (β = .18 in women (p = .17) and

β = .24 in partnered persons (p = .04) for mean emotionality, and β = .21 in women (p = .10) and β = .28 in partnered persons (p = .02) for the APS).

4 Discussion

Studies into the behavioral effects of T have produced mixed results, which is likely to be an important reason why treatment of T deficiency, for instance as the result of aging, is still controversial. As T-dependent arousal might offer an explanation for these mixed results I used an online survey to explore the relation between a person's tendency to become aroused in emotional settings, that is their emotionality, their mental health and their level of expressed T as indicated by their MPH. In the factor analysis I performed four types of emotionality emerged: internalized negative emotionality, positive emotionality, sexual emotionality and externalized negative emotionality. Furthermore, all these types of emotionality were positively correlated, although in a few cases the association was not significant. This suggests that on average people who have a greater tendency to experience highs, also have a greater tendency to experience lows, but that there may be large individual differences as well. Lastly, I found the expected associations between MPH and the main indicators of emotionality and mental health, at least in partnered persons and to a lesser extent in women, though in many participants the level of T was probably too low to be reflected in MPH and in others MPH was so high they were excluded as outliers. The found associations between MPH and mental health and the different types of emotionality were overall as hypothesized, reflecting higher mental health at intermediate levels of MPH, and showing a positive association between general emotionality and MPH. Moreover, they suggest that at least some of these different associations can be found using MPH as an easy to use and non-invasive measure of expressed T, although the measure is probably more reliable if the assessment is done by a trained assessor, especially in men as they have more digital hair than women, and it cannot be used to assess the lowest level of T.

Although the found associations were as expected, it is not clear why they would be limited to partnered persons and women. The fact they were, suggests that only in these groups participants had managed to stay more or less themselves despite the stress and the limitations brought on by the pandemic and the measures to contain it. Indeed, this seems a plausible explanation for the fact that in partnered people there was a link between MPH and the outcome variables, as they would be less affected by the measures that limited social and physical contact with other people. Alternatively, that no link with MPH was found in men, might be because in them this measure is less reliable. They have more MPH, which means their counts may be less accurate, and there may be a relation to body hair that is absent in women. However, on the basis of these results it cannot be ruled out that there simply was no relation between MPH and mental health in men to be found, either because (in them) MPH was not associated with T, or because T was not associated with mental health.

The type of emotionality that emerged as the first factor from the factor analysis was a negative one. Moreover, the scale that was derived from this factor had the strongest correlations to both mean emotionality and the APS. This may be explained by what has been called the asymmetry of emotions (Frijda, 1986). Negative emotions indicate that some need of the individual is not met and as such they stay relevant until the situation has changed for the better, whereas positive emotions signal that all is well and thus will fade faster. Moreover, it seems plausible that negative emotions do not require the absence of happy circumstances, whereas positive emotions are less likely to occur when circumstances are less favorable, which in this study due to the pandemic they were. Thus, there are reasons to assume that under more normal circumstances the found relations between positive emotionality and the other types of emotionality would have been stronger. For comparison, in a study examining the association between T and the Big Five, the only association found was not with the neuroticism scale but with a scale that is associated with positive emotions, namely extraversion (Smeets-Janssen et al., 2015).

Theoretical considerations

In the study of behavior responses are typically assumed to be evoked by stimuli. Therefore, it may seem a stretch that a physiological response like arousal can be a signal of something as complex as a proposition, in this case the unconscious conclusion that a behavior or experience is or will be rewarding. I submit, however, that only in the case of innate, prepared or conditioned reflexes a response is a direct reaction to an element in the situation. To give a simple example, an unexpected loud noise will evoke the startle reflex. Another example might be the reaction to an angry face we see in primates, as an individual will respond to such a face with either an enduring gaze or gaze aversion, depending on their level of T (Van Honk et al., 2014). In other cases I would maintain that behavior and experience are best seen as flowing from the individual's generative world model, meaning that stimuli generate expectations that subsequently help interpret these stimuli, for the most part outside of awareness (e.g. Barrett, 2017; Barrett & Satpute, 2019). Moreover, I would argue that these expectations can only be generated when there is semantic processing outside of awareness (cf. Dijksterhuis & Strick, 2016).

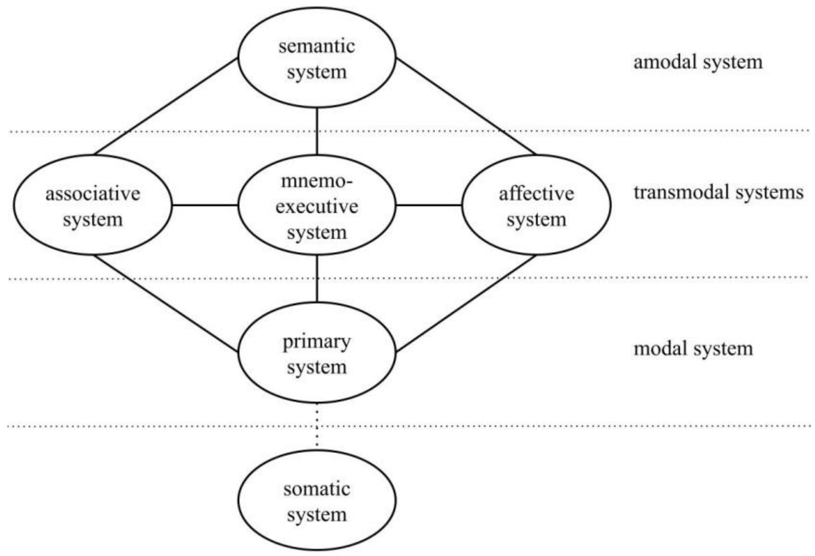
There are good reasons to assume semantic processing involving concepts such as reward and punishment does not require language or consciousness. Firstly, it is probably the most straightforward explanation not only for much of the complex behavior seen in primates, but also for the effects of operant conditioning in other animals. For instance, rats can at least seemingly make causal inferences in a basic task after passive observational learning (Blaisdell, Sawa, Leising, & Waldmann, 2006), and capuchin monkeys will act upset if they see that another monkey gets a bigger reward for an identical response (Brosnan & De Waal, 2003). These examples show that animals act as if they can predict actions, rewards, risks, causes and effects, which I would maintain is hard to do for any animal without eventually acquiring, if they have not already, the concepts *action*, *reward*, *risk*, etc. Moreover, in a single-cell study with macaque monkeys doing a delayed go-no-go task neurons were found that fired during states of expectation of individual environmental events that were predictable to the monkey through its past experience (Schultz, Apicella, Scarnati, & Ljungberg, 1992). Secondly, experiments with neonates suggest how the concepts *reward* and *threat* are developed (Debiec & Sullivan, 2017). For instance, in newborn rat pups, pairing a new odor with a reward not only produces a learned preference for that odor, it also becomes a characteristic of the mother, meaning it can regulate the pup's physiology as if it were the maternal odor. As stimuli are continuously being categorized through interaction in different parts of the brain, ranging from neocortical regions and the medial temporal lobe to the basal ganglia and midbrain dopaminergic systems (Seger & Miller, 2010), it is hard to see how these pups could react with the same response to different types of rewarding stimuli could be possible without developing in this case the concept of reward. The amygdala-dependent threat system, however, does not become functional until ten days after birth, meaning that the pup will respond to predator odors by fleeing or freezing, but not before they have learned what it is like to feel safe and cared for, or how to find their mother for instance (Debiec & Sullivan, 2017). Thirdly, there is growing support for the notion that even after an individual has learned to use language, thought and motivation remain possible outside of awareness (Custers & Aarts, 2010; Dijksterhuis & Strick, 2016). There is evidence for instance that in humans subliminal reward cues improve performance to the same extent as supraliminal reward cues (Bijleveld et al., 2014).

Relatedly, optogenetic experiments with mice have shown that at least in fear conditioning the prefrontal cortex (PFC) is involved during the entire learning process (Kitamura et al., 2017). Cells in the hippocampus keep this semantic part of the fear memory active, together with the cells dedicated to the affective part of this memory in the amygdala, so the two parts of the memory become associated as the neurons in PFC mature. Once this is done, the involvement of the hippocampal cells stops and the amygdala becomes reliant on the signal from PFC. Notably, this finding sheds a new light on the discovery of cells in the human amygdala and hippocampus that fired always and only to very specific persons and objects (e.g. Quiroga, 2019). These so called concept cells have been assumed to code for the persons and objects they fire to. However, I would argue that the ones in the amygdala code only for the evaluation of referents, i.e. not for the referents themselves, and that the ones in the hippocampus serve to coactivate the corresponding concept cells in the amygdala and the 'real' concept cells in PFC, or rather the default mode network, as this seems the network most involved in semantic processing (Binder, Desai, Graves, & Conant, 2009; Satpute & Lindquist, 2019).

Taken together, studies like these suggest that representations in one part of the brain are reiterated in other parts, i.e. the neurons that code for a particular representation in one network are capable of activating the neurons that code for the corresponding representation in another. Thus, physical signals from the individual's environment are translated into modal, i.e. non-semantic representations, that are in turn translated into amodal, i.e. semantic representations, and vice versa (see Figure 4). In general this means that, if relevant enough, a non-semantic representation like the representation of a perceived stimulus activates the corresponding semantic representation, that then leads to an also semantic expectation, that in turn activates the corresponding action or metabolic program, as a result of which the corresponding action or metabolic process will occur. In the case of emotional behavior it means that an unconscious conclusion about the situation leads to the expectation of a particular interoceptive response, after which the occurrence of this response activates this conclusion about the situation even further, thus drawing it into awareness.

Figure 4

The reiteration model of everyday behavior

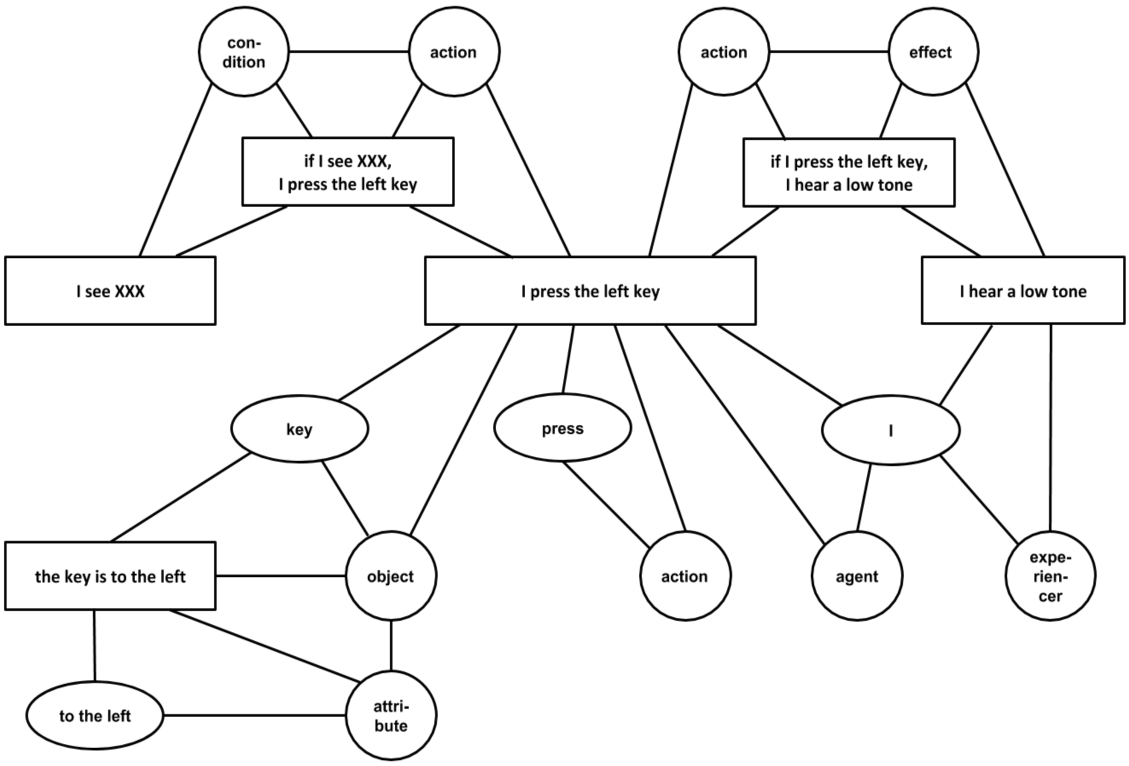


Note. The solid lines represent the possible reiteration loops within the mental system, the dotted line represents the reiteration loop between the mental and the somatic system. Not shown is the third transmodal satellite of the mnemo-executive system, the symbolic system, which is only fully developed in humans.

To some it may still seem unlikely that even babies and animals would have the relational concepts such as *action, cause* and *effect*. However, I would argue that concepts are by their nature elements that are binding and/or bound and thus part of a network (see Figure 5). This means that one cannot acquire concepts that refer to elements in the world like *mummy, good* and *crying*, without acquiring the concepts that specify how these elements are related. Additionally, I would argue that it is precisely because amodal representations are only loosely related to modal representations that they can be processed fast and in parallel, thus through the spreading of activation leading to new inferences outside of awareness (cf. Anderson, 1983; Collins & Loftus, 1975; Mirman & Magnuson, 2009). In conclusion, it may be impossible to find evidence for the hypothesis that T is needed for reward related arousal in a behavioral experiment or using questionnaires, but this hypothesis cannot be rejected with the argument that there are no known mechanisms that could explain how complex unconscious semantic representations could play an important role in emotional behavior.

Figure 5

Example of a semantic network



Note. In this representation of a typical psychological experiment referential concepts are represented as ovals, relational concepts as circles and the conclusions as rectangles.

Limitations and suggestions for future research

This was an exploratory study in which measures were used that have yet to be validated. Moreover, data were collected a year into the COVID-19 pandemic, which must have impacted the participants' emotional lives considerably, as with the exception of partnered men all participants scored unexpectedly low on mental health. For these reasons more detailed explanations of the found associations between MPH and the main outcome variables can only be speculation. Significant results were found, however, showing more or less the expected pattern, which suggests that both the use of MPH as a measure of expressed T and the association between T and reward related arousal merit further investigation.

A major drawback of the employed MPH measure is that it cannot be used to assess the extreme values of T. The measure may be improved, however, by using photos of the participants' hands or having the hair counted by a trained experimenter. This is one of the things that need to be investigated before we can employ it as a regular instrument. Other questions worth examining are what fingers of what hands should be examined, how MPH is related to T in women, if it is also related to estradiol for instance, and whether the genetic predisposition to grow MPH can be assessed by looking at the pilliary pits. Lastly and most importantly, to test if MPH indicates expressed T, more studies should be done to relate MPH and T levels measured in blood or saliva, both to each other and to different arousability measures, i.e. questionnaires such as the ones used in this study as well as physiological responses to emotional stimuli. Moreover, these studies are best done in healthy participants as well as in patients before and after receiving hormonal restitution therapy.

Because the participants' emotional lives were likely to be affected by the pandemic, without a replication it is hard to interpret the results of the used questionnaire or to assess the reliability of the developed scales. For instance, it may very well be, that under more normal circumstances the overall relation between T and mental health is positive rather than negative. The internalized negative emotionality scale may be valid, but as this type of emotionality may be measured equally well or better with a number of already validated instruments, I would argue there is a greater need for instruments that can assess the other types of emotionality, especially positive and sexual emotionality. Furthermore, the initial item pool may be optimized, for example by adding items probing disgust, as these might have added weight to the factor of externalized negative emotionality. Alternatively, it might be interesting to link T to other measures that can be assumed to assess reward related arousal or for instance the Big Five profiles mentioned earlier (Gerlach et al., 2018). Lastly, in this study the focus was on arousal that was related to T, and thus reward or appetitive behavior. This suggests that there may also be a type of arousal that is related to punishment or aversive behavior, and thus other substances such as vasopressin, as this neuropeptide can have anxiogenic and depressive effects (Neumann & Landgraf, 2012).

Finally, in this study I assumed T is needed for the arousal that informs the individual that the thing they are (unconsciously) expecting to do or feel next will be rewarding. I used this assumption to explain the relation between T and emotional behavior, but it might also explain the positive and curvilinear effects T seems to have on cognition (Celec et al., 2015; Holland, Bandelow, & Hogervorst, 2011; Matousek & Sherwin, 2010; Muller, Aleman, Grobbee, de Haan, & van der Schouw, 2005). T-dependent arousal could serve as a signal to the individual that they are close to solving a problem they are confronted with. Getting this signal when it is likely that a strategy will work or an answer is correct, would then enhance performance, whereas getting this signal when there is only a slim chance that something is a good idea, would impair performance. In a study using a cognitive task reaction times after a task switch were higher in people who were low in arousability, as measured by the APS (Kuik, 2021), and in a single administration study men who were given testosterone performed worse on a cognitive task in which the intuitive answer was wrong (Nave, Nadler, Zava, & Camerer, 2017). However, although these studies are in line with the hypothesis that T can have an effect on cognition through its effect on reward related arousal, more studies should be done to see if this is indeed a viable account.

Conclusion

This is the first study using (self-reported) MPH as a marker for expressed T to explore the association between this hormone and mental health in both men and women. Some of the used measures have yet to be validated and data were collected during the COVID-19 pandemic, that was likely to have had a considerable influence on the participants' emotional lives. However, the results found on the main outcome variables showed a relatively consistent pattern, though only in women and partnered persons, suggesting as expected a curvilinear association between T on the one hand and (negative) emotionality and mental health on the other, as well as a linear association between T and general emotionality. These associations can be explained by assuming that T is needed for the arousal that reiterates the idea that a particular response is or will be rewarding. Lastly, MPH showed promise as an easy to use and non-invasive way to measure expressed T.

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