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THE KEY ROLE OF DOPAMINE AS THE NEURAL CORRELATE OF INTRINSIC MOTIVATION AND TRAIT PLASTICITY

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Abstract

Self-determination theory (SDT), a motivation theory, consists of motivation types: intrinsic motivation, extrinsic motivation, and amotivation, where the social environment is important. SDT's motivation orientations are about individual differences in people's tendencies to orient towards environments. The five factor model (FFM), a personality theory, consists of five factors and can be grouped into two metatraits; plasticity: extraversion and openness; and stability: agreeableness, conscientiousness, and neuroticism. Studies show that SDT's motivation orientations and the factors of FFM significantly covary. Intrinsic motivation and trait plasticity have similar features; the desire for exploration, engagement, well-being, and dopamine as neural correlate. The thesis reviews the role of dopamine as the neural correlate of intrinsic motivation and trait plasticity – a relation between motivation and personality. Dopamine and trait plasticity function to attain rewards of uncertainty and explore, but uncertainty is threatening. Salience coding neurons, value coding neurons and a combination of both are related, respectively, to rewards of information, specific rewards and the value of any uncertainty. Intrinsic motivation is related to the value coding neurons, flow via D2 receptors, the salience network, and the seeking system. Conclusions: there are many appealing similarities and rational that relate constructs/mechanisms – motivation is related to personality; can there even be a common construct? However; results based on proposed theories, neuroscientific quality issues, early inconsistent findings of intrinsic motivation mechanisms, and trait stability are speculated to, also, be needed to model intrinsic motivation. Unifying cross-disciplinary work and proposed theories of neural correlates are encouraged.

Keywords: dopamine, intrinsic motivation, metatrait plasticity, personality neuroscience, the five factor model, exploration

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1. Introduction

Parents might mutter over their kids playing video games, that they just waste their time and do not learn anything useful. However, in the end, it might turn out that the parents should have joined the kids in adapting to changes in the environment and learned to play video games. When the kids become adults, they might be better adapted to the current environment, than those who did not play video games, and might acquire advantages from their skills, for example in a well-paid status job, that eventually might increase fitness. New technologies and tools are examples of changes in the environment, in history, that children can show an interest in, learn and then acquire advantages from, while the older generation counteracts change and adaptation. What are the psychology and neural brain underpinnings that are going on that makes this happen? (Di Domenico & Ryan, 2017; Ryan & Deci, 2017; Ryan, Rigby, & Przybylski, 2006; Wilson, 2000)

Humans are born quite undeveloped but have motivation and energy to perform interesting activities by which the individual learns skills and adapt to the current environment, which can increase evolutionary fitness (DeYoung, 2013; Di Domenico & Ryan, 2017; Ryan & Deci, 2017; Wilson, 2000). *Intrinsic motivation* is when people do activities out of pure joy and are activated in novel experiences that increases one’s competence, by exploration and learning (Ryan & Deci, 2000). Researchers have identified common features between intrinsic motivation and trait plasticity. In both intrinsic motivation and trait plasticity, people do activities out of interest and for no other reason than the sake itself, and moreover, a common feature is exploration and personal growth (DeYoung, 2013; Di Domenico & Ryan, 2017). Research shows that motivation is dependent on personality, more specifically, research shows that motivation orientations covaries with the factors of the *five factor model* (FFM; Olesen, 2011a; Persson & Kajonius, 2016).

Another common factor is that it is proposed that the neural correlate of both intrinsic motivation and trait plasticity are the dopamine system. Cues of uncertain rewards increase dopamine levels that mediates behavioral and cognitive exploration, however, uncertainty is both promising and threatening. In more detail; rewards of information activates salience coding dopamine neurons, specific rewards activates value coding dopamine neurons, and trait plasticity is related to activation of both systems. Furthermore, the value coding neurons, the seeking system – related to dopamine, and flow "via" D2 receptors are all related to intrinsic motivation (Bromberg-Martin, Matsumoto, & Hikosaka, 2010; DeYoung, 2013; Di Domenico & Ryan, 2017; Hirsh, Mar, & Peterson, 2012).

The present thesis' primary objective is to review the key role of the neurotransmitter dopamine as the neural correlate of the *self-determination theory's* (SDT) intrinsic motivation and DeYoung's trait plasticity (extraversion & openness to experience), including the relation between intrinsic motivation and trait plasticity.

Di Domenico and Ryan (2017) argue for the importance of having a neuroscientific theory and framework, even if only proposed, and that it has been missing for intrinsic motivation. A theory of the neural correlates of a concept, like intrinsic motivation, and hence, likely also trait plasticity, is valuable as it improves the design of experiments (Di Domenico & Ryan, 2017). Furthermore, Braver et al. (2014) encourages cross-disciplinary interaction and integration to improve and unify knowledge, and it seems reasonable that this is valid also for the topic of dopamine, intrinsic motivation, and trait plasticity.

Motivation is a state and personality is about individual differences. Motivation is changeable and personality is stable. The degree of motivation depends more on the social environment than does personality (trait), even though both nature and nurture are important aspects of personality variations. It is hence, e.g. easier in psychotherapy and coaching to have an impact on motivation, however, the counselor and the client will benefit if they adapt their work and change to the client's trait (Di Domenico & Ryan, 2017; John, Naumann, & Soto, 2008; Olesen, 2011b; Polderman et al., 2015; Ryan & Deci, 2017), and goals that are congruent with one's traits improve well-being (Sheldon, 2008).

Intrinsic motivation and trait plasticity have many interesting similarities but also differences, e.g. high in trait plasticity can be related to antisocial behavior, and hence, I speculate that trait stability is needed to model intrinsic motivation, moreover, the findings have quality issues making it difficult to interpret the results and they are based on proposed theories, however, from prominent researchers, e.g. Colin G. DeYoung and Richard M. Ryan.

Document outline: firstly; the theory of motivation, intrinsic motivation, SDT, framework for viewing motivation and personality, personality science, FFM, metatraits and FFM outcomes will be briefly described, secondly; the role and function of dopamine will be described and covariations analyzed, divided up in: a) a general presentation of dopamine, b) motivational control, c) the seeking system, d) dopamine's relation to trait plasticity, e) two propositions of dopamine's relation to intrinsic motivation and a brief example of other neural correlates, and f) similarities and covariations between intrinsic motivation and trait plasticity, and finally; presentation of concluding thoughts.

Limitations: a) the neurotransmitter dopamine will only be reviewed in relation to the mentioned objectives, b) play is related to intrinsic motivation (Di Domenico & Ryan, 2017) and play will be mentioned but is not an objective, and c), the literature review will have a lack of completeness, not covering all related recent research, and sometimes being brief and shallow as the scope is made up of several major concepts, however, newer material has been prioritized.

2. Intrinsic Motivation and the Self-Determination Theory

In Braver et al.'s (2014) overview of the state in motivation-cognition interactions research, they acknowledge that the area has seen a rejuvenation of interest. The research area develops from three scientific perspectives: 1) personality, social and affective; 2) cognitive, computational and systems neuroscience; and 3) developmental, aging, and lifespan research. Since Wundt and James, the construct motivation has been a central part of psychology. The motivation construct is complex and difficult to define, where one reason is the span of mentioned areas, from social psychology to individual differences to neuroscience. Motivation has been a convenient “catch-all” to explain complex human behavior and people are good at creating post-hoc reasons for behavior, when in fact, for example, the cause was an extraneous unconscious factor (Nisbett & Wilson, 1977). As a partial consequence, motivation is described by countless of constructs, hypotheses, and definitions. For example, a debated issue is if motivation actually is a related construct such as attention, affect, arousal or strategies of high-level decision making. A number of motivational constructs have been suggested, over time, to describe human behavior, for example: intrinsic motivation (Deci & Ryan, 1985), self-efficacy (Bandura, 1977), achievement goals (Dweck, 1986), and need for achievement (McClelland, Atkinson, Clark, & Lowell, 1976), and many lack an established neuroscientific basis, and maybe a not direct motivational construct to mention and consider is FFM (Costa & McCrae, 1992, 2008). Many areas have been working in isolation and are now encouraged to cross-disciplinary integration and interaction (Braver et al., 2014).

Motivation according to social and personality psychology can very briefly be described as; that the individual has motives that give energy and direction, motives in the form of needs, the individuals efficacy, and beliefs about the future. Motivation according to human cognitive neuroscience can very briefly be described as, that; the value of a future event is represented in the brain and that this predicts the individual’s investment of effort (Braver et al., 2014). Wise (2009) summarize the function of motivation and the interdependent function of rewards: motivation is a state variable that energize and forego pursue of goals (Wise, 1987). Hunger and thirst are two typical examples of motivational states, also known as drive states (Lehrman, 1964). The other form of motivation is incentive motivation, were, for example, incentive rewards in the environment makes an organism approach and work for attainment of the reward (Wise, 2009).

2.1. Intrinsic Motivation

Human and animal neuroscience have paid their attention to *extrinsic motivation*, where extrinsic motivation is the behavioral and neural response to extrinsic incentives such as money and food. Intrinsic motivation, in personality and social psychology, on the other hand, is different from extrinsic motivation (Braver et al., 2014), and Deci and Ryan (1985) define intrinsic motivation as the inherent satisfaction and pleasure from being engaged in an activity in itself. This difference was shown in studies were the rewards undermined intrinsic motivation (Deci, Koestner, & Ryan, 1999). The study of intrinsic motivation and extrinsic motivation have used a method called the *free choice paradigm*, were the participants perform a task, like for example a puzzle, and when the task is done, the participant is observed during a free choice period and the time spent, continuing, performing the task is measured. Extrinsic rewards like money tend to shorten the time, and hence, is said to undermine intrinsic motivation (Deci et al., 1999), this phenomenon is, for example, known as the *undermining effect*.

Ryan & Deci (2017) summarizes some characteristics of intrinsic motivation in relation to mammal development: “The phenomenon of intrinsic motivation reflects the primary and spontaneous propensity of some organisms, especially mammals, to develop through activity— to play, explore, and manipulate things and, in doing so, to expand their competencies and capacities” (p. 123). The spontaneous behavioral tendency to curiously interact with new objects and to explore new and novel environments can be considered evidence for intrinsic motivation (Ryan & Deci, 2017). The role model of intrinsic motivation is a child playing, e.g. a two year old kid, as you do not need to motivate a child to play (Deci

& Ryan, 2000). In a similar manner, rhesus monkeys persisted to play a puzzle even though no rewards were presented and since then the term has been applied (Harlow, 1950). Spontaneous play and exploratory behavior have challenged the behaviorist view, that volitional behavior is controlled and dependent on rewards in the organism's environment (Di Domenico & Ryan, 2017).

Intrinsic motivation introduces the organism to new circumstances and environments, which makes the organism learn skills that improve the capabilities of managing an uncertain future and environment. If the organism did not have this inherent satisfaction of learning without rewards, then the organism would be less prone to develop inherent capacities, and less prone to adapt to new domains and changes in the environment, for example, an adaption by learning habits from members of the group and developing new strategies for finding food. This is especially important for the human organism, which has complex habits and a long extended postnatal development. So, from both a developmental and evolutionary perspective intrinsic motivation makes humans more adaptive (Deci & Ryan, 2000; Ryan & Deci, 2017; Wilson, 2000). Additional proof is that intrinsic motivation is one of the most critical factors for learning and performing in school, according to meta-analysis (Froiland & Worrell, 2016; Taylor et al., 2014). Already in 1985 Deci and Ryan proposed that intrinsic motivation is a lifelong psychological growth function (Deci & Ryan, 1985). This natural aspiration maps well to an organismic approach, which is the basis for SDT (Ryan & Deci, 2017).

Activities that are performed for the "rewarding" feeling of enjoyment and out of interest, can be considered intrinsically motivated behaviors, on the other hand, activities that are performed for some separable outcome, for example, social acceptance (shame) and external rewards (money) can be considered extrinsically motivated behaviors. Synonyms to intrinsic motivation are enjoyment, interest and inherent satisfaction, and synonyms to extrinsic motivation are noninherent motivation and instrumental motivation (Deci & Ryan, 2000; Legault, 2017).

2.2. Self-Determination Theory

SDT is an empirically based macro theory, about human motivation and personality, and also well-being, supported by a vast amount of research during four decades. The individual's dependency of and interaction with the social environment play an important role in SDT (Deci & Ryan, 2000; Howard, Gagné, & Bureau, 2017).

SDT posits a multidimensional representation of motivation, where there are different types of motivation and the types have different qualities, making the theory different from many other motivational theories, as they posit that it is about the amount of motivation. Intrinsic motivation and extrinsic motivation are two of the motivation types and there is also a third type denoted *amotivation* – lack of motivation, moreover, extrinsic motivation is made up by several behavior regulation types that are out of scope for the present thesis.

A meta-analysis based on 486 samples and 205000 participants give support for a continuum like structure of motivation and show that SDT is very important in explaining human motivation (Howard et al., 2017). The motivation types span along a continuum were the most autonomous type is intrinsic motivation and the most controlled form is rewards and punishments of extrinsic motivation (Deci & Ryan, 2000; Ryan & Deci, 2017).

SDT is as mentioned an organismic theory – we are inherently evolved to strive for psychological growth. SDT postulates that humans have three basic psychological needs, and moreover, if these needs are met, then psychological growth and development are predicted, and if not, then ill-being and downgrade are predicted. The outcome from satisfaction of the three basic needs is better quality of motivation – more intrinsic motivation – and well-being, and moreover, better qualities of motivation will improve: persistence, performance, creativity, and learning (Deci & Ryan, 2000; Ryan, Huta, & Deci, 2008).

The three basic psychological needs are *autonomy*, *competence* and *relatedness*. Autonomy literally means “self-governing” which implies the experience of regulation by the self, a feeling of that one´s behavior is self-endorsed and in line with one’s interests. Competence is a feeling of mastery and efficacy. Relatedness is a feeling of being connected with and cared for, by other people. All three needs are necessary, analog to essential nutrients, and universal (Deci & Ryan, 2000; Ryan et al., 2008).

The concept of flow is related to SDT’s intrinsic motivation and can be briefly be described as the experience of total absorption of a task, and also, non-self-conscious enjoyment and optimal challenge, however, flow does not recognize autonomy as a factor in flow (Csikszentmihalyi, 1990; Deci & Ryan, 2000).

There are individual differences in motivational style, and according to SDT, people have three different motivational orientations (i.e. *causality orientations*) and they are denoted *autonomy, controlled* and *impersonal orientation*. Referring to a type of orientation or tendency toward the environment – the individual’s interpretation of the given environment – that has developed over time to individual differences. The orientations can briefly be described as follows; a) autonomy orientation: experiencing choices as volitional and free according to people’s own values – related to intrinsic motivation; b) control orientation: experiencing choices as pressured and conflicted by social norms – related to extrinsic motivation, and c) impersonal orientation: experiencing choices as beyond intentional control – related to amotivation (Deci & Ryan, 1985; Ryan & Deci, 2017).

2.3. Framework for Viewing Motivation and Personality

Sheldon (2004) present a multi hierarchal framework, based on Wilson (1998), to explain and consider human behavior. Some of the analysis levels are, from higher to lower: culture, social interaction, personality, cognition, and brain & nervous system. Each level interacts with the preceding and succeeding level, and the higher levels answer the “why” and the lower levels the "how" of behavior, assuming that behavior consists of influences by a nested set of interacting and coacting components. Sheldon (2004) also present, within the personality level of analysis, a four-level sub framework, based on McAdams (1996), containing, from higher to lower, in the same manner as the previous list: self narrative, goals, traits, and needs (Sheldon, 2004). For example, self concordance is based on the match between goals and its two lower levels, traits and needs, that is, the self-concordance construct, which is related to well-being (Sheldon, 2008).

3. The Five Factor Model and Personality Science

If the brain is the source of human behavior, then it is also the source of individual differences in behavior. If two persons on average differ in behavior in similar situations, then their brain structures need to be different. All personality differences are due to biological differences, genetic factors are more obvious than cultural and environmental factors, as they more indirectly have an impact on personality via the brain structures. The field of personality neuroscience is about identifying the neural mechanisms that underlies stable personality differences (Yarkoni, 2015), and stated differently, it is about understanding brain mechanisms that cause individual pattern differences in cognition, behavior, motivation and emotion (DeYoung, 2010a; DeYoung & Gray, 2009).

Personality traits are the intensity and frequency that people have specific cognitive, behavioral, motivational and emotional states. Trait describes relatively stable responses to broad classes of stimuli, an important assumption in many biological based personality theories. Trait is context sensitive but to a broader class of stimuli (Corr, DeYoung, & McNaughton, 2013; DeYoung, 2010a; Fleeson, 2001; Fleeson & Gallagher, 2009).

Personality psychologists study how people differ, what the causes are and their consequences. FFM or big five have reached substantial results in answering how people differ and identifying major dimensions in personality (Allen & DeYoung, 2017; Costa &

McCrae, 1992; John et al., 2008). Questionnaires and lexical assessments of personality have discovered five consistent broad dimensions in personality and the research field is now more researching the causes and consequences, rather than the taxonomy (Allen & DeYoung, 2017).

The five basic dimensions of the FFM are: *extraversion*, *agreeableness*, *conscientiousness*, *neuroticism*, and *openness to experience* (Costa & McCrae, 1992). Each factor or dimension vary on a continuum, and hence, the factors are not types. Each factor is a basic tendency and it is proposed that they have a strong biological foundation. FFM is a hierarchical organization of traits and it is assumed that the five dimensions are the basis for most variations in human personality, and FFM has been replicated in many cultures. Furthermore, FFM is atheoretical (Costa & McCrae, 1992, 2008; Widiger, 2017b).

Big five is synonymous with FFM, however, big five was developed by factor analysis of adjectives, and FFM was developed by factor analysis of questionnaires, the present thesis will use the term FFM. Regarding questionnaires, so are NEO personality inventory-revised the most comprehensive (Costa & McCrae, 1992).

FFM is a framework of personality. It has been successful in enabling an integrative trait model. Findings from a vast amount of various research can be classified and grouped into its comprehensive organizational architecture (Costa & McCrae, 1992, 2008; Widiger, 2017b).

John et al. (2008) conclude that FFM does not meet the highest scientific standards but it does provide descriptive concepts, but lacks a developed theory, and it also provides a nomenclature that is recognized in everyday English. Furthermore, they conclude that research from several groups can be said to have created a paradigm shift in the field of personality and the researchers now have a commonly understood framework and well validated instruments as a basis for their research. However, Widiger (2017b) comment that their statement regarding consensus about the taxonomy might have been overstated.

The five factors were from the beginning assumed to be independent but there is evidence of intercorrelation between them, however, from this came the finding of the two more independent metatraits plasticity and stability (Chang, Connelly, & Geeza, 2012; DeYoung, 2006; Digman, 1997; Widiger, 2017b), but Costa and McCrae (2017) conclude that higher order factors are subtle and the findings are influenced by method biases. The present thesis will be more focused on trait plasticity due to its relation to dopamine and similarities with intrinsic motivation.

Personality states are day to day variations, for example, a very extravert person (trait) will be quiet in the church (state) (Wilt & Revelle, 2017). Personality states can be described as concrete, contextualized and short-term, compared to the more decontextualized and stable personality traits, and moreover, these states can be described in the same way as personality traits and a personality factor’s state is related to its trait (Bleidorn, 2009; Fleeson, 2001).

Yarkoni (2015) gives a critical overview of the field of personality neuroscience and he concludes: a) it is unrealistic to hope to find a one to one relation between a dispositional trait, like one of the five factors, and a neural mechanism, as the neural correlates or biological basis of personality likely is “an enterprise orders of magnitude more complex” (Yarkoni, 2015, p. 41), than at a behavior level describe and measure personality, and b) the relation between specific neural systems and specific traits is difficult to establish, as scientists often opportunistically publish significant results and the major part of all studies has used small samples. Personality neuroscience is a young research area and only very few results, of the neural correlates of FFM, are so well-supported that they can be considered facts (Allen & DeYoung, 2017).

3.1. The Five Factors in FFM

Focus in the present thesis is on extraversion and openness to experiences as they are the shared variance of trait plasticity, and hence a little bit more information will be presented about them. The five factors are presented in the same order throughout the present thesis.

Extraversion includes traits such as activity, assertiveness, sociability and positive emotionality and is described as having a lot of energy to the social world (John et al., 2008). Widiger (2017a) characterize extraversion as: excitement seeking, bold, expressive, lively, active, enthusiastic, sociable, talkative, self-disclosing, poised, warm, friendly, gregarious, adventurous, assertive, outgoing, and energetic.

Extraversion is the most researched of the five factors. One of the most well-known findings in personality is its relation to positive affect and it has an important role in outcomes of well-being (Wilt & Revelle, 2017). Another well-known finding in personality neuroscience is extraversion's relation to and dependency of the dopamine system (Allen & DeYoung, 2017).

The components of extraversion change over the life span; positive affect and sociability increase up to young adulthood and are then stabilized to the fifties, followed by a small decrease. In the same manner, dominance and independence raise up to the thirties and then decrease in the fifties (Roberts, Walton, & Viechtbauer, 2006).

Agreeableness includes traits such as trust, modesty, and altruism, and is described as being directed towards belonging or relating to a community and being positive to benefits of social interaction (John et al., 2008).

Conscientiousness can be described as behavior that is oriented toward achieving goals and related impulse control, characterized as acting according to norms, being able to wait for rewards, think first and take action later, and planning (John et al., 2008).

Neuroticism can be described as negative emotionality such as being nervous, tense and sad, and the opposite being emotional stability (John et al., 2008).

Openness to experience can be described as an orientation towards experiences, including mental experiences, characterized by originality, complexity, breadth and depth (John et al., 2008). Characteristics of open people are their wide span of interest: many and varied hobbies; they like to go to new places and try new things, and; they easily make more creative association of ideas – good thinking skills. Moreover, they have a need for novelty and engage in such activities – they are inherently curious (Sutin, 2017).

McCrae and Costa (1997), by use of questionnaires, focused more on an experiential view of openness, but, when measured with adjective, openness is defined by words such as: intellectual, clever, intelligent, and thoughtful, and there is a relation between openness and cognitive functioning (DeYoung, Quilty, Peterson, & Gray, 2014). Moreover, the relation between openness and intelligence has been debated and is more detailed by subtraits of openness (Sutin, 2017). Openness to experience is also linked to creativity and important life outcomes, such as well-being and every aspect of functioning (Sutin, 2017). DeYoung (2013) denotes “openness to experience” with “openness/intellect”, and from now on in the present thesis “openness to experience” will just be denoted “openness”.

Sutin (2017) summarizes that the search for the neural basis of openness has been problematic due to small sample sizes, in e.g. neuroimaging studies, and she points to diverse results and theories of the neural correlates of openness.

3.2. The Metatraits Plasticity and Stability

Digman (1997) discovered the metatraits beta, referring to personal growth, and alpha, referring to socialization. DeYoung, Peterson and Higgins (2002) labeled them plasticity and stability, were the former refers to beta and the latter to alpha, plasticity and stability are also denotations used by DeYoung (2013). In the present thesis the denotation *trait plasticity* will be used to not confuse the term with “neural plasticity” and, for stability, *trait stability* will be used.

Trait plasticity refers to the shared variance of the traits extraversion and openness, and trait stability to agreeableness, conscientiousness, and negative neuroticism. The metatraits are interindividual stable differences between people. It is proposed that trait plasticity is related to differences in dopaminergic function and trait stability is related to differences in serotonergic function (DeYoung, 2013; DeYoung & Gray, 2009; DeYoung et al., 2002). It is also proposed, that all traits (including sub-traits), i.e. extraversion, openness to experience, openness, intellect, assertiveness, enthusiasm, under the metatrait plasticity are affected by dopamine. However, also withdrawal, politeness, industriousness under the metatrait stability, it is proposed, is affected by dopamine (DeYoung, 2006, 2010a).

There have been several definitions of the metatrait plasticity and DeYoung (2013) summarize these as, expected personal growth, due to a proneness to exploration and being engaged in interesting and novel things and experiences (DeYoung, 2013). Some characteristics of people being high in trait plasticity are: they are good at convincing people; they talk about things in an interesting, varying and expressive way; they are good at generating novel ideas; and, they are inspired by personal growth and learning new things (DeYoung, 2010b). Hirsh, DeYoung and Peterson (2009) found trait plasticity to be related to behavior of being a motivational energizer.

High plasticity and low stability are related to behavior of dramatic forms of exploration such as performing extreme novel scenarios. In behavior of low plasticity, then social morality prevents exploration (DeYoung et al., 2002). In behavior of high plasticity, there is a tendency to antisocial behavior, aggression, and impulsivity (DeYoung, Peterson, Séguin, & Tremblay, 2008).

3.3. Well-being Outcomes

A constant and very strong predictor of well-being is personality. Particularly extraversion (positive), agreeableness (positive), conscientiousness (positive), and neuroticism (negative) have been shown to be correlated to all components of subjective well-being, supported by a vast amount of research, and openness (positive) was significantly related to happiness, job satisfaction, quality of life, but not to negative affect, life satisfaction and overall affect (DeNeve & Cooper, 1998; Steel, Schmidt, & Shultz, 2008). Weiss, Bates and Luciano (2008) suggest, based on evidence from twin studies (N=973), that the genetic variance, i.e. the difference in genetic architecture, that explains FFM also completely explains the heritable differences in subjective well-being, concluding that subjective well-being and personality are linked by common genes.

4. The Role of Dopamine

Dopamine is a neurotransmitter in the brain and has a function of signaling between nerve cells. The brain has several dopaminergic pathways of dopamine neurons that synthesize and release the neurotransmitter dopamine, example of major pathways: the mesolimbic pathway, the mesocortical pathway, and the nigrostriatal pathway. The mesolimbic pathway signal from the ventral tegmental area (VTA) of the midbrain to the ventral striatum of the subcortical basal ganglia. The mesocortical pathway signals from the VTA to the prefrontal cortex. The nigrostriatal pathway signals from the substantia nigra pars compacta (SNc) in the midbrain to the caudate nucleus and putamen in the dorsal striatum. It has an effect on motivation, reward and learning; motor function; cognition and emotion; and, attention (Bromberg-Martin et al., 2010; Gazzaniga, Ivry, & Mangun, 2013)

It is related to disorders such as: drug abuse and addiction, parkinson’s disease, schizophrenia, ADHD, and bipolar disorder. Some example of substances or drugs that affect the neuro transmitter: l-dopa, amphetamines, cocaine, and methylphenidate. Even though these drugs are related to drugs used for pleasure, dopamine is related to motivation and desire, and not the pleasure in itself, as opioids, by a motivational incentive salience signal, representing the value of the reward, that makes the organism take action for attaining the reward. Incentive salience is associated with approach behavior and aversive salience is associated with avoidance behavior (Bromberg-Martin et al., 2010; Gazzaniga et al., 2013).

Dopamine is a complex neuromodulator system that governs activities in a wide variety of motivational and cognitive processes. Aspects that make the system complex are that dopamine originates in and projects to multiple parts of the brain, and also, that there are two classes of dopamine; D1-type and D2-type, were D1-type is made up of two receptors; D1 and D5, and D2-type is made up of three receptors; D2, D3, and D4, with varying distribution over brain areas (DeYoung, 2013).

The neurotransmitter systems of serotonin, acetylcholine, adenosine, and norepinephrine have strong and well-known interactions with the dopamine system (Daw, Kakade, & Dayan, 2002; McClure, Gilzenrat, & Cohen, 2006; Salamone et al., 2009; Sarter, Gehring, & Kozak, 2006).

Note that, dopamine in the brain is related to more things than only responses to rewards, for example, arousing and aversive stimuli (Horvitz, 2000), and moreover, brain dopamine is maybe not required for the function of rewards, that is, reward learning has been shown in dopamine-deficient mice (Robinson, Sandstrom, Denenberg, & Palmiter, 2005).

4.1. Dopamine and Motivational Control

Dopamine has an accepted role after a substantial amount of research and this conventional theory will briefly be presented, however, the present thesis is also based on Bromberg-Martin et al.’s (2010) proposed theory from 2010, and their theory will also be presented briefly, in relation to the topic of the present thesis, and moreover, their theory is also applied and elaborated further in the following proposed theories for intrinsic motivation and trait plasticity.

The conventional general theories state that dopamine has a single homogeneous neural signal – a single signal. Dopamine originates primarily from the VTA and the SNc, and the neurons project to the cerebral cortex and subcortical areas (Björklund & Dunnett, 2007). Dopamine is transmitted via the neurons in two modes: phasic and tonic (Grace, 1991). In the *phasic mode*, large dopamine concentration is obtained in downstream areas by intense firing rates, from 0.1 to 0.5 seconds (Schultz, 1998, 2007). These short bursts below or above baseline represent inactivity or activity in response to related events and cause an increase or decrease of dopamine in target structures, which can last for seconds. Many types of reward related cues and rewards trigger phasic signals (Schultz, 1998) and these are involved in motivation control, including being an incentive signal in reward seeking (Berridge & Robinson, 1998) and in reinforcement learning being the teaching signal (Schultz, Dayan, & Montague, 1997; Wise, 2005). In the *tonic mode*, a normal function of relevant neural circuits is obtained by a steady baseline level – constant firing – of dopamine in downstream areas, to target structures (Schultz, 2007).

The tonic mode can be associated with animals' exploratory seeking behavior. The phasic mode can also activate the seeking behavior when specific cues of incentive motivation information cause an action-oriented effect. Furthermore, it is proposed that this seeking behavior, activated by a phasic mode, function best if the levels of tonic dopamine is relatively high (Alcaro & Panksepp, 2011).

Dopamine responds strongly to rewards and is hence important in motivation. It has several important functions, for example, learning what is bad and what is good and to select actions to avoid bad things and experience good things. Dopamine signaling is, hence, important for creating memories of cue-reward associations (Dalley et al., 2005) and generating a state of motivation for reward seeking (Berridge & Robinson, 1998; Salamone, Correa, Farrar, & Mingote, 2007). Dopamine is important for establishing goals and being in a state of 'wanting' that motivates activities to attain the goal, so dopamine is not necessarily pleasure and 'liking' (Berridge & Robinson, 1998; Palmiter, 2008). The strength of synaptic connections between neurons increases, it is hypothesized, when dopamine supports reinforcement learning, and this would make an organism, by use of trial and error, learn how to optimize actions to gain rewards (Goto, Yang, & Otani, 2010; Lisman & Grace, 2005; Molina-Luna et al., 2009; Surmeier et al., 2010).

During rewarding experiences dopamine should be released to motivate activities that lead to rewards, for example, phasic 'bursts' of activity is produced when primary rewards as water and food are presented (Schultz, 1998). However, studies show that the dopamine neurons are triggered by the size of a *reward prediction error* that informs about the difference between the estimated expected reward and the actual received reward. If the reward is smaller than expected, then the dopamine neurons would be inhibited, and if the reward is larger than predicted, then dopamine neurons would be excited. The same principle, for the dopamine neuron, is valid for information about sensory cues that can lead to future rewards (Houk, Adams, & Barto, 1995; Montague, Dayan, & Sejnowski, 1996; Schultz et al., 1997).

Research shows that dopamine neurons are more complicated than previously thought and that they are not just coding of a single homogeneous signal, instead there are different types that code non-rewards and rewards in different ways. To handle this issue Bromberg-Martin et al. (2010) propose the following hypothesis.

Motivational salience signals are sent to and coded by motivational salience coding dopamine neurons, which is excited by both aversive and rewarding events. Motivational value signals are sent to and coded by value coding dopamine neurons, which is inhibited by aversive events and excited by rewarding events. Alerting signals are sent to both salience and value coding neurons, and the alerting signal is triggered by sensory cues that are unexpected and highly important. Salience coding neurons orient attention to cues that triggered the alerting signal, by use of motivational and cognitive resources. Value coding neurons activate seeking of environments, for cues of alerting signals, so that important outcomes can be predicted (Bromberg-Martin et al., 2010).

These three types of signals: alerting, value, and salience, together, control motivation behavior and coordinate downstream brain structures. Brain systems for cognitive processing, attentional orienting and motivational drive are supported by motivational salience coding dopamine neurons. Brain systems for value learning, seeking goals and evaluating outcomes are supported by motivational value coding dopamine neurons (Bromberg-Martin et al., 2010).

Also, the anatomical location and projections of motivational salience coding and motivational value coding dopamine neurons are hypothesized. Dopaminergic neurons originating in the SNc and VTA, release dopamine in many brain areas: extended amygdala, hypothalamus, hippocampus, basal ganglia, and frontal cortex. Salience coding neurons and value coding neurons are distributed as a gradient between SNc and VTA, were SNc contains more salience coding neurons and VTA contains more value coding neurons. This distribution and the projection of dopamine neurons creates different exploration versions, due to different responses to stimuli of uncertainty (Bromberg-Martin et al., 2010).

Brain regions for general motivation, orienting, and cognitive processing are active in motivational salience coding. Dorsolateral SNc and medial VTA are the main locations of motivational salience coding neurons and they can send signals to areas of the dorsal lateral prefrontal cortex (DLPFC), the dorsal striatum and the nucleus accumbens core (NAc core). This is, for example, supported by that the dorsal and lateral frontal cortex is involved in cognitive functions such; as decision making of motivational outcome, cognitive control, working memory, and attentional search (Kable & Glimcher, 2009; Lee & Seo, 2007; Wallis & Kennerley, 2010; Williams & Castner, 2006; Wise, 2008). Furthermore, the dorsal striatum is engaged in all salient events and is related to general motivation, attention, orienting, working memory, and motivational salience coding, and moreover, the dorsal striatum is engaged in learning the values of action related to motivational value coding (Hikosaka, Takikawa, & Kawagoe, 2000; Klingberg, 2010; Palmiter, 2008). In addition, during stress, dopamine is released, due to aversive stimuli, in the amygdala, an indication of activity in the salience system (Pezze & Feldon, 2004).

Brain regions for avoidance and approach, value learning, and outcome evaluation are active in motivational value coding. Ventromedial SNc and throughout VTA are the main locations of motivational value coding neurons and they can send signals to the ventromedial prefrontal cortex (VMPFC), dorsal striatum and nucleus accumbens shell (NAc shell) (Williams & Goldman-Rakic, 1998). This is, for example, supported by that the orbitofrontal cortex (OFC) is part of the VMPFC (Porrino & Goldman-Rakic, 1982) and a lot of research, from functional imaging studies (Jensen et al., 2007; Litt, Plassmann, Shiv, & Rangel, 2011) and single neuron recording (Morrison & Salzman, 2009; Roesch & Olson, 2004), support OFC's involvement in value coding.

4.2. The Seeking System and Mammalian Exploration

Mammals have an exploratory seeking system that keeps the mammals engaged with the environment, that is, it functions as an objectless appetitive system. The seeking system is hardwired to spontaneously energize many types of foraging – seeking for food - and exploratory activities. Panksepp uses the aphorism that seeking is “a goad without a goal” and that it searches without a goal until it finds something rewarding and then learns and develop. Mammals explore, experience new objects and integrate new information, if not, they might end up less adaptive to changes in their environment. The basic urge for seeking develops into more complex cognitive and behaviorally adaptions of exploration (Panksepp, 1998; Panksepp & Biven, 2012). The seeking system has many similarities with the described organismic perspective and Di Domenico and Ryan (2017) find these converging findings very telling.

In a rat the main core structures of the seeking system are: NAc, VTA, VMPC and the projections from VTA that support these brain areas (Panksepp, 1998; Panksepp & Biven, 2012).

4.3. Dopamine, the Neural Correlate of Trait Plasticity

DeYoung (2013) puts forward a unifying theory that describes how all personality traits that are related to exploration depend on dopamine, based on a general definition of exploration as any cognition or behavior that is motivated by an incentive reward value of uncertainty, that is, he assumes that individual differences in response to uncertainty are explained by dopamine and that the overall function of the dopaminergic system is exploration. If dopamine is released anywhere in the dopamine system, then the motivation for behavioral and cognitive exploration increases (DeYoung, 2013).

Uncertainty or the unknown has the ambivalent feature of being both innately promising and innately threatening (Peterson, 1999). Regarding being innately threatening, it is based on a theory that anxiety increases if the *psychological entropy* increases. Moreover, the entropy model of uncertainty (EMU; Hirsh et al., 2012) is the basis of DeYoung’s (2013) expanded concept of psychological entropy. Humans can be viewed as an information system were entropy measures the extent of disorder in the system (Boltzmann, 1877; Shannon, 1948). Humans are also *cybernetic systems*, in the way that humans are self-regulating and goal-directed (Carver & Scheier, 1998; DeYoung, 2010b; Van Egeren, 2009), and the entropy of a cybernetic system is related to the uncertainty of its capacity to pursue goals (Wiener, 1961). A human, consciously and unconsciously, registers information about: a) the goal, b) current status in relation to the goal, and c) the capabilities or operators of acquiring the goal (DeYoung, 2010b; Newell & Simon, 1972). Note however, that this is a simplification, as humans have many goals, goals are hierarchically structured and of different types (DeYoung, 2013). Uncertainties in these three types of information (a, b and c above) increases the psychological entropy, which is correlated to an increase in anxiety. If uncertainty is high it makes it more difficult to reach the goal - the uncertainty is aversive (Hirsh et al., 2012).

In DeYoung (2013) a theory is presented that is an extension of Hirsh et al.'s (2012) description of EMU, in that psychological entropy is also innately incentively rewarding. That is, stimuli that are uncertain is both simultaneously promising, i.e. rewarding, and threatening (Peterson, 1999) or simply stated as "everything both good and bad comes initially out of the unknown" (DeYoung, 2013, p. 3). Rewards are stimuli that give a cue of movement towards a promising goal or achievement of a goal, the former is denoted incentive rewards and the latter consummatory rewards. An unpredicted event can make an organism react in two different competing ways: exploration or caution (Gray & McNaughton, 2000). Based on this, DeYoung (2013) define exploration as "any behavior or cognition motivated by the incentive reward value of uncertainty" (p. 1).

DeYoung (2013) adds that humans have a desire for acquiring information and that this is enabled by exploration, for the rewarding incentive value of information, in a similar manner as for specific rewards such as food and money. In a fMRI study, curiosity increased when answers to simple questions were shown and this was correlated with activity in the dorsal striatum, and moreover, the participants put time and resources to the get the answers. People spend as much time and resources to acquire typical rewards as they do for the reward of information (Kang et al., 2009). Animals and humans like environment with more predictable information and this have been shown in several studies (Bromberg-Martin et al., 2010; Herry et al., 2007).

DeYoung's (2013) theory is based a lot on Bromberg-Martin et al.'s (2010) comprehensive model of the dopaminergic system, as earlier described. The model state that there are two types of dopaminergic neurons that are triggered by three types of input. One type of dopaminergic neuron is the salience coding and the other is the value coding. The two types of neurons get activated or inhibited by unpredicted rewards and unpredicted punishments, i.e. value and salience type of signals, the third type of input activates both types of neurons by stimuli of an alerting signal, i.e. an unexpected sensory cue (Bromberg-Martin et al., 2010). DeYoung (2013) expands Bromberg-Martin et al.'s (2010) theory, in that, both salience coding and value coding neurons are triggered by unpredictive incentives, and moreover, that all exploration is enabled by the dopamine release as a reaction to these unpredictive incentive rewards. The activation of salience coding by unpredictive incentive is the new theoretical extension, as the value coding has been known, and furthermore, that cues for the value of information trigger salience coding neurons (Depue & Collins, 1999; DeYoung, 2013).

This brings together a unifying theory that cognitive exploration and behavioral exploration is based on the reward value that uncertainty gives and that this is mediated by dopaminergic activity (DeYoung, 2013). Activation of the salience system is linked to the trait openness, activation of the value system is linked to the trait extraversion, and global levels of dopamine is linked to trait plasticity (extraversion & openness) (DeYoung, 2006). All other dopamine related traits are proposed to be linked to these three traits or their sub-traits (DeYoung, 2013). DeYoung (2013) summarizes that if one would ignore history, then one could have created a trait that could have one of these denotations: exploration, engagement, interest, or curiosity, and that the neural basis of the trait would be the dopamine system, and moreover, the trait would also be very related to trait plasticity. DeYoung (2013) identifies the dopaminergic system as “the potentiation of exploration” (p. 5).

Dopamine has a varying impact on personality and it is linked to all traits that represent variations of exploration processes. Were exploration, as earlier defined, is energized by the incentive reward value that a promising uncertainty provides, hence, dopamine related traits are assumed to be the traits that express differences in people’s response to uncertainty (DeYoung, 2013). An exploratory response to cues of information would be due to dopamine activity in the salience system. An exploratory response to cues of specific rewards would be due to dopamine activity in the value system. An exploratory response to the incentive value of all kind of uncertainty would be due to global levels of dopamine. The impact of the dopaminergic system on cognition, motivation, behavior and emotion, for individual differences, is more complex than this, for example, difference; in receptor types, between phasic and tonic firing patterns, in synaptic clearance and in reuptake mechanism. DeYoung (2013) concludes, that currently, the salience and value coding systems are sufficient for the suggested theory of dopamine’s impact on personality.

DeYoung (2013) summarizes that the only evidence of trait plasticity, as an effect of global tone of dopamine affecting both the salience and value coding system, is that dopamine is involved in both extraversion and openness.

As earlier mentioned, plasticity does not refer to “neural plasticity”. The denotation is more related to plasticity or stability of cybernetic elements. Plasticity is suggested to be the tendency of the cybernetic system to generate new ways to reach a goal, new evaluations of the current state, and new goals. Stability is suggested to be the tendency of a person to stay focused on the goal and resist deviations, for example, by not being distracted by impulses and having stable goals (DeYoung, 2013).

Two needs are satisfied with plasticity and stability: the need of plasticity, to explore changing uncertain environments and hence improving adaption to create effectiveness for goal pursuit, and the need of stability so that goals can be acquired. Stability and plasticity is not opposed, they are rather in tension of each other. A well performing cybernetic system is both high in plasticity and high in stability. For example, if plasticity is high and stability is low, then exploration might be hindered by high aversion. The opposite of stability is instability and the opposite of plasticity is rigidity. The assumed function of trait plasticity is the same as the proposed function of dopamine - explore and acquire rewards of uncertainty. Note that, trait plasticity implies that both openness and extraversion are of a similar magnitude (DeYoung, 2013; DeYoung et al., 2002).

4.4. Dopamine, the Neural Correlate of Intrinsic Motivation

The increasing neuroscientific knowledge about trait plasticity and its correlation with dopamine, the commonalities between trait plasticity and intrinsic motivation, and a missing common framework for the neural basis of intrinsic motivation is background to the neuroscientific theories of intrinsic motivation that Di Domenico and Ryan (2017) propose, and experimental neuroimaging research that is not based on a guiding theory are more likely to have errors.

Proposition I. Their first proposition is that intrinsic motivation is supported by a dopaminergic system. It is likely that intrinsic motivation is dependent on several neural structures or systems as intrinsic motivation is a complex behavioral, cognitive and affective phenomenon, so the neural basis might be a broad neurotransmitter system. There are three types of evidence that dopamine is the main neural substrate for intrinsic motivation (Di Domenico & Ryan, 2017).

The first evidence is that dopamine is similar to intrinsic motivation in that dopamine is related to: creativity, persistence, cognitive flexibility, positive affect, and that novelty likely causes explorative behavior. Importantly, positive affective states are related to ‘wanting’, an energized appetitive, not ‘liking’, a consummatory hedonic effect related to opioids (Berridge, 2007; Di Domenico & Ryan, 2017; Kringelbach & Berridge, 2016).

The second evidence is that the mammalian seeking system is the system that underlies intrinsic motivation and the seeking system drives exploratory behavior that is similar to intrinsic motivation, and a main component in the seeking system is dopamine (Di Domenico & Ryan, 2017; Panksepp, 1998; Panksepp & Biven, 2012). Mammals have intrinsic motivation for exploration and play, making the mammal more adaptive (Di Domenico & Ryan, 2017; Wilson, 2000). However, caution is needed when generalizing evidence from mammal studies to human population, but Di Domenico and Ryan (2017) claim that affective neuroscience, based on a mammal neuroethological view, is consistent with the concept of human intrinsic motivated exploration (Panksepp, 1998; Panksepp & Biven, 2012; Ryan & Deci, 2017).

The third evidence is evidences of a direct link between dopamine and intrinsic motivation. One study (N=233) found, using self-report questionnaires of flow, that during mandatory activities such as work and studying, people with a gene variant of the dopamine D2 receptor more easily got into flow (Gyurkovics et al., 2016), and flow is related to (or mediated by) intrinsic motivation (Deci & Ryan, 1985, 2000). Another study that used positron emission tomography (N=25, r=0.41) found correlation between the availability of dopamine D2-receptors and proneness to experience flow. The correlated activity was mainly in the dorsal striatum, with a higher correlation in the putamen. The study concludes that one’s proneness to get into flow is dependent on individual differences in the dopaminergic neurotransmission (de Manzano et al., 2013). Based on this evidence, Di Domenico and Ryan (2017) hypothesize that the most important neural substrate of intrinsic motivation is dopamine, however these empirical studies are the only ones that they have found that study a direct link between dopamine and intrinsic motivation.

They also propose that intrinsic motivation activities are correlated to a high rate of dopaminergic signaling within the value coding system. The neural circuit that is activated in reward value processes and reinforcement learning is activated also when there are no rewards but only performance feedback, for example by positive and negative feedback, and moreover, this activity can be affected by motivational context, for example the learner's goal. Intrinsically motivating activities are characterized by clear goals, immediate feedback and almost manageable challenges, and note that, this type of activity is not fully unexpected, a condition proposed by DeYoung for dopamine activity. The involved neural circuit is dopaminergic target input regions, e.g. VMPFC and striatum (Ryan & Deci, 2017; Tricomi & DePasque, 2016).

Di Domenico and Ryan (2017) argue that intrinsic motivation is regulated in some complex form of phasic and tonic modes of dopamine transmission, and that there is not enough research to elaborate on how it is performed, and that they hence leave the issue out of scope. One example of this has already been described, were the right level of tonic, optimized the seeking behavior.

Di Domenico and Ryan (2017) refer to the information-gap hypothesis of curiosity, by Loewenstein (1994), when pointing to DeYoung's (2013) statement, that the possibility of gaining information triggers a salience related exploration, characterized by desire of information and curiosity. Interest and curiosity are well known features of intrinsic motivation and the authors suggest that the salience coding system is the basis of intrinsic motivation (Di Domenico & Ryan, 2017).

Di Domenico and Ryan (2017) reason, if the neural basis of intrinsic motivation is the proposed dopamine system, then intrinsically motivated activities should be related to brain activity in the most important areas of the dopaminergic system. Some neuroimaging findings related to the dopaminergic value system will now be reviewed and then, the dopaminergic salience system will be very briefly reviewed in a following chapter, together with Di Domenico and Ryan's (2017) second proposition that intrinsic motivation is related to specific large scale networks.

Murayama, Matsumoto, Izuma and Matsumoto's (2010; N=28) fMRI study of rewards' undermining effect on intrinsic motivation shows that the effect is related to the midbrain and caudate. The experimental group got reduced activity in the areas when the rewarding money was withdrawn, meanwhile the control group maintained its previous activity. Di Domenico and Ryan (2017) conclude that this is consistent with the suggested model that, meanwhile performing intrinsically motivated activities, cues of task-related progress trigger the dopamine value system.

In another study by Murayama et al. (2015; N=31) success feedback gave more brain activity in the VMPFC (i.e. medial orbitofrontal cortex and bilateral gyrus rectus) than failure feedback, but this effect was reduced at free-choice trials that increased autonomy. However, the outcome of the increased autonomy was improved performance. It is suggested that this is due to value coding neurons from midbrain to VMPC that are involved in update of expectancies and negative reward prediction errors in the learning process. Also, this is consistent with activity within the dopaminergic value system and intrinsic motivation, and moreover, perceived autonomy is a need that enables intrinsic motivation (Di Domenico & Ryan, 2017).

Also, evidence from electroencephalography (EEG) studies is mostly consistent with the relation between intrinsic motivation and the dopaminergic signaling, even though small sample sizes and varying results give that more research with larger sample sizes is needed. Feedback-related negativity (FRN) and error-related negativity (ERN) are two negative peaks in EEG recordings. The FRN appears 200 – 350 ms after negative feedback and the ERN 100 ms after errors. It is suggested that FRN and ERN appear when phasic reductions in dopamine transmission signal from midbrain to anterior cingulate cortex (ACC; Holroyd & Coles, 2002). They are understood as learning signals that tune the ACC so that optimal behavioral performance is obtained, similar to the reward-prediction signaling of value coding neurons (Bromberg-Martin et al., 2010; Schultz, 2007). Results from two studies are briefly described, as examples of evidence. Performance related rewards while performing a challenging task reduced FNR amplitudes, compared to a control group (Ma, Jin, Meng, & Shen, 2014; N=36). Having the option of choice while performing an intrinsically motivated task was related to larger FRN amplitudes (Meng & Ma, 2015; N=18).

Proposition II. Their second proposition is that intrinsic motivation may be related to activity within three large scale brain networks: The central executive, the default mode and the salience. However, the findings and evidence are mixed, and the authors suggest more research (Di Domenico & Ryan, 2017). There are neuroimaging studies that support the proposed relation between the three networks (Klasen, Weber, Kircher, Mathiak, & Mathiak, 2012; Lee & Reeve, 2013; Marsden, Ma, Deci, Ryan, & Chiu, 2015; Murayama et al., 2015, 2010; Ulrich, Keller, Hoenig, Waller, & Grön, 2014).

For example, Lee, Reeve, Xue and Xiong (2012; N=10) in their fMRI-study analyzed if the neural basis is different between extrinsic motivation and intrinsic motivation. They studied the reasons for chosen activity and found that extrinsic reasons showed activity in the posterior cingulate cortex (PCC) and intrinsic reasons showed activity in the insular cortex.

The central executive network involves the posterior parietal cortex and DLPFC (Di Domenico & Ryan, 2017), the default mode networks involves the PCC and MPFC (Gusnard & Raichle, 2001), and the salience network involves the dorsal ACC, anterior insula (AI), as well as, amygdala, NAc, SN and VTA (Bromberg-Martin et al., 2010; Menon, 2015; Menon

& Uddin, 2010). The central executive network and the default mode network, over time, have a contrary activity rate in an antagonistic manner, so that, when the central executive network is active, then the default mode network is passive, and vice versa. The salience network and the AI is involved in modulating the activity of the two other networks (Menon, 2015; Menon & Uddin, 2010). Furthermore, there are not so much knowledge about the role of dopamine in the salience network, but the authors reason about a theory for their relation, which is out of scope for the present thesis (Di Domenico & Ryan, 2017).

Di Domenico and Ryan (2017) suggest that the relation between the networks may describe three characteristics of intrinsic motivation: a) outcome of intrinsic motivation is improved learning, cognitive flexibility and enhanced performance (Grolnick & Ryan, 1987), the reason for this might partly be due to a better mobilization of the central executive network (Ryan & Di Domenico, 2016), b) characteristics of intrinsic motivation is cognitive focus and not being aware of enjoyment of the task (Csikszentmihalyi, 1990; Nakamura & Csikszentmihalyi, 2014), due to increased activity within the executive network, for increased external attention, and also due to, decreased activity of the default mode network, which is commonly related to, for example, rumination and self-reflection (Di Domenico & Ryan, 2017), and c) that intrinsic motivation and autonomy is related to activities that are meaningful and important for the individual, enabled by a bottom-up cognitive process based on visceral and sensory information – a function of the salience network (Di Domenico & Ryan, 2017; Menon, 2015; Menon & Uddin, 2010).

Other neural correlates of intrinsic motivation. There is other research on the neural correlates of intrinsic motivation, and the undermining effect. However, the neural correlates have not yet been researched extensively. One example is Legault and Inzlicht’s (2013; N=43&55) study; they used neuroscience to study causality and neural correlates of improved self-regulation, based on its relation to autonomy orientation, i.e. intrinsic motivation. They found that intrinsic motivation improved the self-regulation process, by stronger emotional reactions and attention to performance errors, and related it to a specific performance monitoring function of the ACC.

4.5. Similarities and Covariations

The first section of this chapter briefly describes some similarities and differences between intrinsic motivation (autonomy orientation) and trait plasticity (extraversion & openness). The second section describes covariations and relations between motivation orientations and FFM.

Similarities. Di Domenico and Ryan (2017) identify some common features between intrinsic motivation and trait plasticity. They see similarities in that both are about creating and performing novel experiences and actively being engaged in the options that the environment provides (DeYoung, 2010b). Moreover, they put forward that trait plasticity has not been described by use of SDT’s autonomy construct, however, if high in trait plasticity then people would perform exploration for no other reason than the desire itself - a goal in itself - and engage in exploration of goals, even when the exploration does not take you closer to the goal itself. They also, see similarities in the neural correlate of a dopamine system, and differences, in that intrinsic motivation refers to a motivational state and trait plasticity refers to a dispositional trait (DeYoung, 2013; Di Domenico & Ryan, 2017).

Covariations. Olesen (2011a) hypothesize a relation between SDT’s motivation orientations and FFM as they both predict similar variables, for example, outcomes of well-being, and that there might be a conceptual overlap between the concepts. The rest of this section summarizes some findings regarding the covariation between motivation and personality, and more specifically covariations between SDT’s three motivation orientations, i.e. causality orientations, and the five factors of FFM.

Deponte (2004) found in her study that impersonal orientation was related negatively to extraversion and conscientiousness, and positively to neuroticism, that autonomy orientation was related to agreeableness and extraversion, and that control orientation was related negatively to agreeableness. Moreover, openness to experience was not related to causality orientation.

Koestner and Losier (1996) found that *reflective autonomy* and *reactive autonomy* are only slightly positively related: “there is no necessary relation between feeling like the origin of one's actions and resisting interpersonal influence” (p. 488). Where reflective autonomy is Deci and Ryan’s conceptualization of autonomy and reactive autonomy is personality psychology’s conceptualization. Impersonal orientation was negatively related to reflective and reactive autonomy. Agreeableness was negatively related to control orientation (Koestner & Losier, 1996).

The construct *authenticity* is similar to the construct autonomy and the more authenticity, the more extraverted, agreeable, conscientious, non-neurotic, and open to experience (Sheldon, Ryan, Rawsthorne, & Ilardi, 1997), and the same is valid for the construct *autonomy support* (Lynch, La Guardia, & Ryan, 2009).

Olesen (2011a) concludes that his study give support for that FFM – dispositional traits – is distinguished from individual differences – orientations – in SDT. The model in Olesen’s (2011a) study, supports the conceptual distinction between traits and motivation orientations. Olesen (2011a) summarize that the study gives evidence to the existing research, including Olesen, Thomsen, Schnieber and Tønnesvang’s (2010) study. Ryan and Deci (2017) summarize Olesen’s findings and state that the nature of motivation orientations, as being a person’s interpretation of a construed environment, makes it distinct from personality traits and FFM.

However, the concepts' factors are significantly correlated and covaries; impersonal orientation was negatively related to extraversion (-.38) and openness (r = -.26) but positively related to neuroticism (.56); and control orientation was negatively related to openness (-.28) and agreeableness (-.54); and autonomy orientation was positively related to extraversion (.22), agreeableness (.25), and openness (.30). Furthermore, FFM is explained by motivation orientations, the significantly explained variance (R^2) for; autonomy orientation was .31, control orientation was .55, and impersonal orientation was .72 (Olesen, 2011a, p. 464).

To provide an overview, the present thesis' author has conceptually summarized and assumed the findings from the presented research results in Table 1, i.e. the author's suggested conclusions based on the presented results. The table describes, if SDT's motivation orientations (factors) and FFM factors are correlated and if it is a positive correlation, negative correlation, or no/unknown correlation.

Table 1

Assumed conceptual correlation between SDT's motivation orientations and the five factors of FFM

Motivation orientation	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness
Autonomy	+1	+1	+1	-1	+1
Control		-1			-1
Impersonal	-1		-1	+1	-1

Note. The author's suggested summary and assumptions based on the presented research results. SDT's motivation orientations = causality orientations. +1 = the provided results are conceptually summarized and assumed to have a positive correlation, a real value is not estimated. -1 = the provided results are conceptually summarized and assumed to have a negative correlation, a real value is not estimated. Blank cell = the provided results are conceptually summarized and assumed to have no correlation or unknown, based on the presented results.

5. Concluding Thoughts

Intrinsic motivation and trait plasticity covary, partly based on that SDT's autonomy orientation, a motivational orientation style, significantly covaries with the traits extraversion and openness, and trait plasticity is the shared variance of these two traits (e.g. DeYoung, 2013; Olesen, 2011a). Furthermore, intrinsic motivation and trait plasticity have common features in both behavior and outcome, and they also have a common neural basis in that both are related to dopamine (DeYoung, 2013; Di Domenico & Ryan, 2017).

Even though motivation is a state and is more dependent on the environment - a faster process, and trait is about individual differences and is more dependent on both nature and nurture – a slower process, these individual differences likely have an impact on the individuals' motivational state, as well as on the individuals' personality state (e.g. Fleeson, 2001; Polderman et al., 2015; Ryan & Deci, 2017; Wise, 2009).

In a large perspective, it can be generalized as motivation is strongly dependent on personality and covaries, in the same manner as for example subjective well-being is strongly linked to personality (e.g. Olesen, 2011a; Sheldon, 2008; Steel et al., 2008; Weiss et al., 2008), even though Olesen (2011a) conclude that statistically SDT's motivational orientations are distinguished from FFM, but at the same time, show significant covariance between all the motivational orientations and the factors of FFM.

One reason that makes intrinsic motivation and trait plasticity covary may be the neural basis of a common dopamine system. DeYoung (2013) assumes that the function of dopamine and trait plasticity is the same, and that the function is to attain rewards of uncertainty and explore, but uncertainty is not only rewarding it is also threatening; cues of information are related to the salience system and the trait openness, cues of specific rewards are related to the value coding system and the trait extraversion, and the value of any type of uncertainty is related to both the salience and value coding system, i.e. global levels of dopamine, and trait plasticity. The salience coding system is related to cognitive processing, attentional orienting and motivational drive. The value coding system is related to value learning, seeking goals and evaluating outcomes. The salience coding neurons and value coding neurons are distributed as a gradient between SNc and VTA, and the difference in distribution and projection creates differences between individuals. Projections, that relate to the functional areas, for the salience coding neurons are: DLPFC, dorsal striatum and NAc core, and for the value coding neurons: VMPFC, dorsal striatum and NAc shell (Bromberg-Martin et al., 2010; DeYoung, 2013). However, DeYoung (2013) acknowledges that this is a simplification as the system is more complex than this.

Di Domenico and Ryan (2017) have three main evidences of intrinsic motivation's relation to dopamine: a) e.g. dopamine is related to novel exploration, creativity and 'wanting', b) the exploratory behavior of the seeking system is consistent with human intrinsic motivation, and makes the organism more adaptive, and c) there are direct links between dopamine and intrinsic motivation; three links were found that related D2 receptors to flow, which is related to intrinsic motivation. Furthermore, intrinsic motivation is related to: a high rate of dopamine in the value coding system, curiosity, and dopamine's relation to the salience network that govern the antagonistic shifting of activity between the central executive network and the default mode network. Di Domenico and Ryan (2017) differentiate from DeYoung's theory (2013), in that performance feedback activates the value coding system, even when there are no rewards.

However, dopamine's relation to intrinsic motivation and trait plasticity, is partly based on proposed theories that are based on assumptions, and both main review articles

(DeYoung, 2013; Di Domenico & Ryan, 2017) are partly based on Bromberg-Martin et al.'s (2010) review article, which contains a proposal based on a synthesis of previous theories, and moreover, Di Domenico and Ryan's (2017) article's theory is influenced from DeYoung's (2013) article.

In addition, (personality) neuroscience is a relatively new research area and the complexity is greater than the earlier behavioral research areas (i.e. without the neuroscience), and it turns out that neuroscience has quality issues that make the evidence difficult to interpret, for example, sample sizes have been small and there has been an opportunistic publishing of results, though, more valid for older results (Allen & DeYoung, 2017; Yarkoni, 2015). In favor of the proposed theories are, according to my understanding, that the rational and evidence seems reasonable, and that e.g. DeYoung and Ryan are prominent researchers within their research areas.

DeYoung (2013) reasons, in relation to dopamine and trait plasticity, that if one would ignore history, then dopamine related functionality and behavior, maybe, would have a different name, and he gives some examples of names: exploration, engagement, interest or curiosity. In a similar thought experiment, ignoring history, one can do a more extreme generalization and create a common construct or concept for intrinsic motivation and trait plasticity and then, the same given examples would be useful candidates for denotation. There are many commonalities, for example: novel experiences, exploration for the sake itself, personal growth, and well-being. There are also differences, for example, trait plasticity is a metatrait in personality describing individual differences, in human behavior, and intrinsic motivation is about motivation, and more dependent on the environment and the motivational state, and moreover, intrinsic motivation is also activated by performance feedback, even if the feedback is not related to rewards, and moreover, differences are also described in the following paragraph. In support of a theory that covers both individual differences and similarities, the framework of SDT, for example, already manages this issue (e.g. DeYoung, 2013; Di Domenico & Ryan, 2017; Ryan & Deci, 2017). A common construct or concept would decrease the amount of existing constructs and concepts, and hence, provide a more simplified and harmonized arena of motivation, hopefully, without losing quality, and moreover, Braver et al. (2014) encourage cross-disciplinary interaction and integration to improve and unify knowledge within the science of motivation.

When DeYoung et al. (2002, 2008) describe behavior of high levels of trait plasticity as, a tendency to antisocial behavior, aggression, and impulsivity; and, in combination with low stability, as a dramatic form of exploration as well as high aversion; and, in addition, an overall perspective of the present thesis, I get a feeling that this is different from intrinsic motivation, which I have not understood as having these down sides and being more "harmonious". I speculate and suggest that to model intrinsic motivation, one could analyze, if trait stability should be taken into account, which is proposed to reflect a serotonergic function. Some possible rational for this are: a) there are dopamine related traits that fall within trait stability, such as withdrawal, politeness and industriousness (DeYoung, 2006, 2010b), b) the metatraits are to some extent correlated (Costa & McCrae, 2017), c) a well performing cybernetic system is both high in trait plasticity and trait stability, and high in intrinsic motivation is related to well-being and performance (e.g. DeYoung, 2013; Ryan & Deci, 2017), and d) there are more significant covariations between motivation orientations and FFM factors, than the referred to relation between autonomy orientation (intrinsic motivation) and extraversion & openness (trait plasticity), see Table 1, e.g. autonomy orientation is indicated to, also have some correlation with agreeableness, conscientiousness and neuroticism, that makes up trait stability.

I think there may be more knowledge potential in analyzing and exploring more lower level concepts and constructs, i.e. more specific brain processes, using neuroscience, for example, as Legault and Inzlicht (2013) did when studying self-regulation, that is related to intrinsic motivation, and found a related performance monitoring function of the ACC. Based on Di Domenico and Ryan (2017) and the presented research results of the neural correlates of intrinsic motivation, I think the findings are varied and with quality issues (e.g. sample sizes), and does not yet, to my understanding, provide a consistent model of the underlying system of intrinsic motivation.

One important benefit of the proposed theories of intrinsic motivation is according to Di Domenico and Ryan (2017), that it is useful to have a proposed theory, lacking something better, when designing experiments, and I assume this is valid also for trait plasticity. Future studies that validate the proposed theories, hence, seem important.

I think the forces behind what makes some people explore new goals and some people being stable continuing pursuing set goals, and related; life span variations, evolutionary gain of functionality and differences between individuals are important. An increased understanding of motivation and personality, similarities and differences, I believe can have a great impact on, for example, personal development, such as psychotherapy & coaching, and education, by adapting to the individual's personality and humans underlying biological mechanisms (e.g. Di Domenico & Ryan, 2017; Froiland & Worrell, 2016; Olesen, 2011b; Sheldon, 2008).

Moreover, ending where I started the present thesis, the underlying forces of engagement, interest and sometimes dependency appearing behavior of video games, social media, and virtual worlds are likely related to rewards of uncertainty and the dopamine system (e.g. DeYoung, 2013; Di Domenico & Ryan, 2017; Ryan et al., 2006).

6. References

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