EYE MOVEMENTS, TRAIT IMPULSIVITY, AND HYPOMANIA PRONENESS IN HEALTHY YOUNG ADULTS

by

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Eye movements, trait impulsivity, and hypomania proneness in healthy young adults

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Abstract

Bipolar disorder is defined as a brain disorder characterized by extreme mood fluctuations that result in changes in energy and disability. Enhanced impulsivity is present in episodes of mania or hypomania in bipolar disorder, of particular importance are factors of impulsivity such as inability to predict or anticipate future events. Delineating trait versus state components of impulsivity helps identify risk factors for bipolarity and evaluate disease progression. Eye movements have been used to assess impulse control as well as predictive and anticipatory mechanisms. Here, we use a subsyndromal approach to relate eye movement measures to impulsivity and hypomania proneness in a cohort of young adults not previously diagnosed with a psychiatric disease. We assessed 60 participants (20 males, 40 females) in the antisaccade task, and a smooth pursuit battery that include a sinusoidal pursuit paradigm and a predictive pursuit task. Participants additionally completed the Hypomanic Personality Scale and Barrat Impulsiveness Scale. We found positive relationships of small effect size between mean number of express saccades in antisaccade trials and deceleration after target extinction in predictive pursuit with hypomania proneness. We also show a negative trend of small effect size between initial eye acceleration with hypomania proneness. Given that we tested healthy participants and assessed hypomania proneness, our results might suggest a state-related component of impulsivity. However, all results must be interpreted with caution as none are statistically significant.
Lay Summary

Bipolar disorder is a brain disorder that causes extreme mood swings and leads to impairments in normal function, impulsive decision-making, and eye movement deficits. Here we wanted to study whether impulsivity acts as a risk factor or rather is a consequence of this disorder. To distinguish between these two concepts, we assessed healthy, young participants proneness to experiencing hypomania, which is a milder form of the extreme mood state known as mania. Our participants completed a set of cognitive assessments and a battery of eye movement tests that measure impulse control and prediction. We found relationships between our eye movement measures and cognitive tests that resemble what patients with bipolar disorder show compared to controls. Our findings must be interpreted with caution but might suggest that impulsivity acts as a risk factor rather than a consequence of the disorder.
Preface

My supervisor, Dr. Miriam Spering, along with committee members Dr. Trisha Chakrabarty and Dr. Ivan Torres were responsible for the initial study question. We later worked together to modify it in a feasible way that matched both my interests and the gaps in knowledge. I then pieced the question apart and created the research objectives and hypotheses that frame this thesis. Along with Dr. Spering, Dr. Chakrabarty, and Dr. Torres we designed the tasks and decided on the cognitive assessments. I was fully responsible for all participant recruitment, data collection, data preprocessing, and analysis. Dr. Spering gave mentorship and expertise in eye movement data analysis and result interpretation.

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List of Abbreviations

BD = bipolar disorder

BIS-11 = Barratt Impulsiveness Scale 11 Ed.

FEF = frontal eye field

HPS = Hypomanic Personality Scale

KBIT-2 = Kaufman Brief Intelligence Test 2 Ed.

MT = middle temporal

MST = medial superior temporal

SC = superior colliculus

SEF = supplementary eye field
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To my parents for trusting my strength, my brother for always being there, and my dog Bruno for never leaving my side.
Chapter 1: Introduction

Bipolar disorder is defined as a brain disorder characterized by extreme mood fluctuations that result in changes in energy and the ability to function (American Psychiatric Association [APA], 2013). This disorder affects approximately 45 million people worldwide (James et al., 2018) and onset typically peaks in early adulthood (20-30 years; Tondo et al., 2009). People affected by bipolar disorder (BD) alternately experience episodes of mania and depression, separated by periods of relative mood stability (euthymia). Among the deficits associated with BD are cognitive impairments in neuropsychological domains like attention, memory, and executive function (Jiménez et al., 2018; Martínez-Arán et al., 2004). These deficits are predominantly present during acute episodes of mania and depression, but may remain during euthymic states and even during remission (Ancín et al., 2010; Krabbendam et al., 2005). Even though these deficits have a devastating impact on quality of life, the extent to which executive functions are affected in patients with bipolar disorder is still a matter of debate (Ramírez-Martín et al., 2020). Furthermore, it is unclear whether cognitive deficits are preceding risk factors for bipolarity (i.e., whether they act as traits) or whether they occur as a consequence of the disease (i.e., states).

This thesis aims at addressing the trait vs. state question by examining impulsivity—a hallmark cognitive-executive deficit in bipolar disorder—in a population of healthy, previously undiagnosed adults and relating it to bipolarity trait. Impulsivity is measured using established self-assessment questionnaires as well as eye movement tests that can provide sensitive indicators of impulse control function. In the following paragraphs, I will provide a background to our current understanding of bipolar disorder, cognitive-executive functions with a focus on impulse control, and eye movements in healthy adults and those with bipolar disorder.
1.1 Bipolar disorder: clinical diagnosis, etiology, and neural correlates

Individuals who live with BD cycle through episodes of mania and depression. These mood states are defined by the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; APA, 2013) and encompass a set of criteria that must be met to diagnose the episode and the disorder. According to the DSM-5, mania refers to “a distinct period of abnormally and persistently elevated, expansive, or irritable mood and abnormally and persistently increased goal-directed activity or energy” (APA, 2013, p. 124). During periods of mania, three or more of the following symptoms are significantly present and represent a change in usual behaviour: inflated self-esteem or grandiosity, decreased need for sleep, increased talkativeness, flight of ideas or racing thoughts, distractibility, increase in goal-directed activity or psychomotor agitation (i.e., non-goal-directed activity), and/or excessive involvement in risky behaviours. The distinction between hypomania and mania is defined in the DMS-5 and pertains to the duration of the symptoms, with a hypomanic episode lasting at least four days and a manic episode lasting at least one week (APA, 2013). A depressive episode refers to a state where five or more of the following symptoms are present during the same two-week period: depressed mood, loss of interest or pleasure in almost all activities, significant unintentional loss or gain in weight or appetite, sleep disturbances, psychomotor agitation or retardation, tiredness or fatigue, excessive self-reproach or guilt, recurrent thoughts of death or suicidal ideation, and/or impaired ability to think, concentrate, or make decisions (Smith et al., 2012). Finally, euthymia refers to the state between episodes in which BD patients do not experience mood disturbances. It is important to note that BD is one of the most impairing mood disorders. Death by suicide or suicide attempts are present in close to half of BD patients (Grande et al., 2015) and there is a significant
comorbidity with substance use disorders, which is associated with poor treatment outcome (Swann et al., 2004).

Although the etiology of this disorder remains unclear, research has identified consistent alterations in the brain function and connectivity of BD patients. Firstly, inflammatory cytokines and immune cells have been found to be elevated in both blood and cerebrospinal fluid during the symptomatic episodes of the disorder (Sayana et al., 2017). Second, structural irregularities have been found in both grey (ENIGMA Bipolar Disorder Working Group et al., 2018) (Hibar et al., 2018) and white matter brain volumes (ENIGMA Bipolar Disorder Working Group et al., 2019) in BD. Lastly, alterations in dopamine and serotonin neurotransmitter signaling (Martino et al., 2020) and resting state brain activity have been identified in subcortical-cortical functional connectivity between thalamus, limbic network, and frontal cortex (Skåtun et al., 2018). Recent efforts to elucidate the physiological basis of the disorder proposed a mechanism that is traced back to immune dysregulation mediating white matter alterations in the limbic network. This dysregulation leads to a destabilization of neurotransmitter signaling, specifically within dopaminergic and serotoninergic systems. According to the authors, these signaling changes then lead to abnormal cortical-subcortical coupling that ultimately manifests in the clinical symptoms and deficits associated with the disorder (Magioncalda & Martino, 2022).

Research on the neural basis of executive function deficits in those living with BD has focused predominantly on patients with a BD diagnosis, restricting knowledge to disease states and, generally, making it subject to effects of medication (Damme et al., 2017). The concept of hypomanic personality emerged from the need to study individuals at high risk of developing BD to investigate disease etiology (Eckblad & Chapman, 1986). This led to a body of research addressing proneness to hypomania in healthy individuals. Using a longitudinal approach, one
study reported that individuals with higher scores in the hypomanic personality scale (HPS; Eckblad & Chapman, 1986) are significantly more likely to develop BD later in life. After 13 years, Kwapil and colleagues found that 28% of high scorers presented hypomanic episodes compared to 3% of controls and 25% qualified for a BD diagnosis compared to none in the control group (Kwapil et al., 2000). Hypomania proneness has also been assessed and related to cognitive functions (Gruber et al., 2021; Mason et al., 2012; O’Sullivan et al., 2011), neural connectivity in reward circuitry (Damme et al., 2017) and in prefrontal cortex (Peterson & Harmon-Jones, 2008), and neural activity in response to anger-evoking events (Harmon-Jones et al., 2002).

Studying traits, as opposed to states of BD is crucial as it provides insight into whether cognitive deficits are preceding risk factors or begin during symptomatic episodes of the disease. Additionally, this delineation might allow the assessment of cognitive deficits in general and impulsivity in particular as measures of disease progression and treatment efficacy.

1.1.1 Impulsivity as a hallmark symptom of BD: definition, neural correlates, and measurement.

Impulsivity is predominantly evident during manic episodes, but can remain present in other mood states and even during remission (Najt et al., 2007; Saddichha & Schuetz, 2014; Strakowski et al., 2010). Impulsive behaviour is generally described as a propensity to hasty, expeditious responses or reactions to both internal and external stimuli and events and arises without regard of consequences. Impulsivity is a multidimensional construct that comprises a wide set of behaviours such as lack of premeditation, failure to inhibit motor responses, bias for
immediate reward, among others (Dalley et al., 2011). Patton and colleagues (1995) proposed a three-factor framework of the components of impulsivity, comprising 1) attentional impulsiveness, i.e., the lack of ability to focus on a given task; 2) motor impulsiveness, i.e., acting in the spur of the moment; and 3) non-planning impulsiveness, i.e., lack of self-control or inability to plan carefully and accordingly. Noteworthy for this thesis, lack of premeditation or non-planning impulsiveness comprise an important factor of the impulsivity construct and are related to the inability to predict or anticipate future events (Dalley et al., 2011).

Research on the neurophysiological basis of impulsivity has related it with monoamine function in distinct networks in the brain (i.e., the limbic network and cortico-striatal pathways). Specifically, the dopamine and serotonin systems have been identified in both animal and human studies to play a role in impulsive behaviours (Dalley & Roiser, 2012). Dopaminergic systems originate in the ventral tegmental area and substantia nigra and give rise to pathways that connect to striatal, cortical, and limbic networks (Kandel et al., 2021). Serotonergic systems originate in the Raphe nuclei and connect with multiple cortical, limbic, and midbrain areas that include the basal ganglia (Kandel et al., 2021). Overall, the literature supports the notion that impulsivity depends on the interaction between different brain networks and involves multiple neurotransmitter systems (Dalley & Roiser, 2012).

Impulsivity research has largely relied on self-reports, for instance, questionnaires such as the Barratt Impulsivity Scale (BIS; Patton et al., 1995), or the UPPS Impulsive Behaviour Scale (Miller et al., 2003). Prepotent response inhibition tasks, i.e., tasks that assess the ability to suppress an already initiated or reflexive response, have also been used to quantify impulsive behaviour (Go/No-Go task; Donders, 1969; Stop-Signal task, Logan & Cowan, 1984; see Fig. 1.1; anti-saccade task, Munoz & Everling, 2004; see Fig. 3). In essence, these types of tasks
consist of a sensory stimulus used to trigger a reflexive motor response such as a button press or a rapid shift of the eyes (termed a saccade). There are trials in which the triggered motor response is appropriate and trials where it is not and must be inhibited. Impaired performance in these tasks is usually represented by reaction time (the time it takes from stimulus presentation to the response) and increased commission errors (i.e., incorrect response to the stimulus) and/or omission errors (i.e., no response to the stimulus).

**Figure 1.1.** Schematics of behavioral measures of impulsivity. A. Stop-Signal task (Logan & Cowan, 1984). B. Go/No Go task (Donders, 1969)
Research on impulsivity in BD, using either self-report inventories or one of the behavioural tasks described above, shows diverse findings. On one hand, BD patients report significantly higher scores than controls in inventories like the BIS and UPPS (Bauer et al., 2017; Mazzola-Pomietto et al., 2009). Correspondingly, response time (Mazzola-Pomietto et al., 2009; Strakowski et al., 2010) and commission errors (Fleck et al., 2011) are elevated in Go/NoGo and Stop-Signal task as compared to controls. On the other hand, some studies found no differences in either reaction time or error rate between BD patients and controls in the Go/NoGo task (Cheema et al., 2015; Hummer et al., 2013; Kaladjian et al., 2009).

Some of these heterogenous findings might be due to the nature of BD progression and treatment, because all these studies are subject to the effects of multiple medications (e.g., antidepressants, mood stabilizers, antipsychotics). Specifically, variable effects of medication have been found in the Stop-Signal task (Bersani et al., 2016; Strakowski et al., 2009) and antisaccade task (Keedy et al., 2014; Reilly et al., 2014). However, many studies do not state an assessment of possible confounding effects of medication (Bauer et al., 2017; Kaladjian et al., 2009; Kopf et al., 2019).

In summary, whereas self-reports consistently reveal elevated levels of impulsivity in BD patients, laboratory tests yielded inconsistent findings, in part likely due to various effects of medication. As a result, it is still unclear whether impulsivity plays a role as a trait or state characteristic in BD. The current thesis aims at further investigating this question and relies on eye movements as a potentially sensitive measure to do so. Prepotent response inhibition paradigms like the Stop-Signal Task and Go/NoGo task can be adapted to obtain the motor response through eye movements. In general, eye movements are highly suitable as measures of higher-order cognitive processes such as decision-making (Spering, 2022), and may provide an
avenue to investigate impulsive behavior (Hutton, 2008). In the following paragraphs, an overview of the eye movement literature in healthy and pathological populations will be provided.

1.2 **Eye movements: types, functions, and neural correlates**

Eye movements have been used as a probe for sensory, motor, and cognitive processes for over a century. The human eye movement repertoire includes rapid movements that shift gaze to an object of interest, termed saccades. The examination of saccade components like latency (i.e., time from initiation to execution of the movement), velocity, accuracy, and range of motion give insight into the normal function of neural circuitry (Termsarasab et al., 2015). Eye movements that continuously and slowly track a moving object are referred to as smooth pursuit. Smooth pursuit eye movements are closely linked to how we process visual motion information and are predominantly driven by a visual motion signal (Berryhill et al., 2006). Compared to saccades, pursuit has latencies that typically ranges within 100 to 150 ms of an object’s motion onset (Tychsen & Lisberger, 1986). During its initiation phase, pursuit is the direct result of visual motion input (open-loop pursuit). During the later, closed-loop pursuit phase, it is also influenced by extraretinal signals such as internal feedback (efference copy or corollary discharge, proprioceptive signals) as well as by cognitive factors such as expectation (Wu et al., 2021). The properties measured to evaluate smooth pursuit function include latency, eye velocity, acceleration, and gain (i.e., the ratio of eye velocity to target velocity). In addition to shifting our gaze to objects of interest, we also use fixational eye movements to stabilize gaze on stationary
objects. Other types of eye movements are used to keep objects focused across depth planes (vergence) or to compensate for self-motion (vestibulo-ocular reflex; Leigh & Zee, 2015).

Eye movements result from the interaction of sensory signals (e.g., visual and auditory information) and high-level processes (e.g., attention, memory, decision-making, learning). A notable process that takes part in the generation and execution of eye movements is anticipation. Research has shown that the expectation of a target or event will result in a saccadic eye movement before the event occurs (Findlay, 1981). Similarly, the anticipation of a motion signal is enough to trigger a smooth pursuit eye movement (Barnes, 2008).

For the purpose of my thesis, I will focus on saccades and smooth pursuit eye movements as two types of human oculomotor response to visual stimulation. Saccades and smooth pursuit are controlled by joint brain networks that include distinct areas in the cortex, midbrain, brainstem, and cerebellum (see Fig. 1.2). Visual information from the retina travels to and is decoded by the visual sensory areas in the occipital cortex (V1-4). The lateral intraparietal area (LIP) is associated with the encoding of visual target location, and it contributes to the planning and execution of saccades (Bisley & Goldberg, 2003). The superior colliculus (SC) is a midbrain structure that serves as a central hub for integrating visual, motor, and sensory information related to eye movements and it contributes to target selection. The frontal eye field (FEF) is responsible for generating signals that direct eye movements towards specific locations in space (Bruce & Goldberg, 1985). Supplementary eye fields (SEF) are involved in the preparation and initiation of voluntary saccades and have been implicated in the control of both saccades and smooth pursuit, as well as the predictive component of these eye movements (Leigh & Zee, 2015). Additionally, smooth pursuit eye movements also rely on the middle temporal (MT) and medial superior temporal (MST) cortical areas, the brain’s motion processing centres (Movshon
et al., 1990). Then, cerebellar areas like the flocculus are involved in the adaptive control of eye movements and contribute to the fine tuning of pursuit eye velocity based on visual motion signals. The cerebellar vermis contributes to the coordination and accuracy of eye movements (Krauzlis, 2005). Finally, the brainstem pontine nuclei neurons signal the execution of the movement that is carried out by the appropriate set of extraocular muscles (Kandel et al., 2021). Because eye movements are controlled by a vast network of brain areas, they are also found to be impaired in many different groups of diseases (Wong, 2008).

**Figure 1.2.** Neural pathways for the generation and control of eye movements. Connections between cortical structures (yellow), subcortical nuclei (green), and cerebellar nuclei (purple) subserve the oculomotor system. Figure adapted from Kandel et al., 2013 (Orban De Xivry & Lefèvre, 2007). Created with Biorender ®.
1.2.1 Eye movements in BD: saccadic and pursuit impairments

Ocular motor dysfunction has generally been identified across the schizoaffective spectrum that includes disorders such as schizophrenia, schizo-affective disorder, and BD (Trillenberg et al., 2004; Wolf et al., 2021). In this thesis, I will focus on BD, and hence will provide an overview of the literature on eye movement impairments in this population here.

With regard to saccade performance, patients overall seem comparatively normal in their performance. They do not differ from healthy controls in either saccade accuracy or latency of visually-guided saccades, and they are relatively unimpaired in memory-guided saccades (Gooding & Basso, 2008). Similarly, BD patients performing pursuit tasks make initial saccades during pursuit that are comparable to those made by healthy controls. These findings suggest that visual motion information is extracted accurately by the saccade system in this population (Sweeney et al., 1999).

Whereas sensorimotor performance in standard saccades tasks seems relatively unimpaired, specialized saccade tasks have revealed deficits in BD patients. The antisaccade task (Munoz & Everling, 2004), a paradigm developed to investigate ability to inhibit a reflexive movement, has revealed that BD patients make significantly more direction errors (i.e., saccade to the target during an antisaccade trial), more anticipatory errors (i.e., saccades made between the gap onset and 80 ms after target onset), and fewer corrections (i.e., saccade to the correct location after an erroneous saccade) as opposed to healthy controls (Gooding & Basso, 2008; Reilly et al., 2014; Tien et al., 1996; Yep et al., 2018). These findings suggest failure to inhibit a reflexive saccade in the BD population. Moreover, first-degree relatives of BD patients have also shown increased antisaccade error rate as compared to healthy controls (Reilly et al., 2014),
indicating that this task sensitively picks up deficits in asymptomatic relatives and performance is consistent with a “trait” biomarker. Similarly, a study that used a saccade version of the Stop-Signal task found longer reaction times in BD patients relative to controls (Thakkar et al., 2015).

Moreover, smooth pursuit has been found to be significantly slowed in BD patients. Pursuit velocity (Kathmann et al., 2003; Sweeney et al., 1999), initial eye acceleration, and pursuit gain (Brakemeier et al., 2020) are reduced across the initial (open loop) and later (closed loop) phases of pursuit in this population, as compared to healthy controls. Generally, lower pursuit eye velocity gain produces higher retinal image motion (motion blur), impairing perception of moving images. BD patients and undiagnosed first-degree relatives share characteristic deficits in oculomotor function (Kathmann et al., 2003).

In light of these findings, we will assess the use of eye movement measures in the context of impulsiveness and hypomania proneness. Table 1.1. describes oculomotor measures that have been used in the literature and their cognitive correlates in the context of impulsivity and mania in bipolar disorder. We correlated these measures with hypomania proneness based on impulsiveness being the core feature of a hypomanic episode. With this, the present study aims to assess general oculomotor function, as well as response inhibition, and scale it to hypomania proneness and trait impulsivity.
Table 1.1. Eye movement measures and their cognitive correlates.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Cognitive correlates</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Antisaccade error rate</strong></td>
<td>An error in the antisaccade task reflects a lack of inhibitory control. Impulse and bipolar disorders patients have increased error rates.</td>
<td>Aichert et al., 2012; Yep et al., 2018</td>
</tr>
<tr>
<td><strong>Antisaccade latency</strong></td>
<td>Reflects on the ability to initiate a voluntary response.</td>
<td>Muñoz &amp; Everling, 2004</td>
</tr>
<tr>
<td><strong>Prosaccade latency</strong></td>
<td>Decreased reaction times in response inhibition tasks are reported for bipolar disorder patients with increased impulsive behaviours.</td>
<td>Swann et al., 2009</td>
</tr>
<tr>
<td><strong>Express saccades</strong></td>
<td>Reflexive, expedited responses that reflect no cognitive processing between incoming sensory stimuli and outgoing motor command.</td>
<td>Muñoz &amp; Everling; 2004</td>
</tr>
<tr>
<td><strong>Smooth pursuit</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gain</td>
<td>Reflects on the accuracy of the tracking and the ability to use efferent feedback information to modify movement. Is decreased in bipolar disorder patients.</td>
<td>Barnes, 2008; Spering et al., 2013</td>
</tr>
<tr>
<td>Phase lag</td>
<td>Reflects on the predictive ability of the pursuit system driven by internal delays in afferent and efferent signaling.</td>
<td>Barnes, 2008; Lencer &amp; Trillenberg, 2008</td>
</tr>
<tr>
<td><strong>Predictive pursuit</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial eye acceleration</td>
<td>Reflects on the pursuit system’s ability to use visual motion information and initiate the movement. Is decreased in bipolar disorder patients.</td>
<td>Trillenberg et al., 2017</td>
</tr>
<tr>
<td>Deceleration after occlusion</td>
<td>Observers continue to pursue during brief periods of target blanking. The deceleration rate after target occlusion reflects predictive ability.</td>
<td>Trillenberg et al., 2017</td>
</tr>
<tr>
<td>Acceleration prior to target reappearance</td>
<td>Reflects on the use of previous target trajectory information and anticipation of a future event (target reappearance).</td>
<td>Bennett &amp; Barnes, 2003, 2004, 2006</td>
</tr>
</tbody>
</table>
Chapter 2: Study design and results

2.1 Study goals and hypotheses

This study aims to investigate the relationship between impulse control function and proneness to hypomania in a cohort of young adults, not diagnosed with any mood disorder, in order to distinguish whether impulsivity has a trait- or state-relationship with hypomania proneness. It relies on the use of self-report inventories to assess hypomania proneness and trait impulsivity, as well as an intelligence tests to control for cognitive capabilities. Importantly, it includes the assessment of visually-driven eye movements (saccades and smooth pursuit) in tasks that probe the ability to accurately control and inhibit eye movement responses. Ultimately, this research can contribute to the question whether eye movements can sensitively reflect impulsivity as it relates to hypomania proneness.

2.1.1 Hypotheses

(1) Hypomania proneness and failure to inhibit reflexive eye movements in the antisaccade task (i.e., antisaccade error rate) are positively related: higher hypomania scores are associated with higher error rates.

(2) Hypomania proneness and prosaccade latency are negatively related: higher hypomania scores are associated with shorter latencies.
(3) Hypomania proneness is related to predictive and anticipatory aspects of smooth pursuit: we expect to see a negative relationship between both predictive saccades in sinusoidal motion and anticipatory acceleration during occlusion with hypomania proneness.

2.2 Methods

2.2.1 Participants

We tested $n = 60$ healthy young adults (20 males, 40 females, $M = 23.5$ yrs, SD = 4.1 yrs). Inclusion criteria were no history of bipolar disorder or neurological illnesses, no concussion within the past two years, no history of eye diseases, no current use of psychotropic medication, and no current experience of symptoms of depression. The Center for Epidemiologic Studies Depression scale [CES-D; see Appendix A], a scale developed as an epidemiologic tool to assess for depression symptoms in the general population (Radloff, 1977), was used as a screening tool. To ensure normal or corrected-to-normal visual acuity (20/20 or better), participants were tested using a Bailey Lovie acuity chart (Multimedia Center, School of Optometry, University of California, Berkeley, CA, USA) at a 4-metre distance. Participants with corrective lenses were asked to wear them during testing. All experimental procedures were approved by the University of British Columbia Behavioural Research Ethics board. Participants gave written informed consent at the beginning of the session and received $20 remuneration. All participants were included in at least one task. One participant was excluded from the study because of ineligibility ($S01; CES-D$ score >16). Two participants were excluded from the
antisaccade task analyses (S08 and S17) due to abnormal performance and technical issues, respectively. One participant was excluded from both sinusoidal and predictive pursuit tasks (S06) due to excessive signal loss from the eye tracker.

2.2.2 Cognitive assessments

2.2.2.1 Kaufman Brief Intelligence Test (KBIT-2):

The KBIT-2 is a test generally used to assess cognitive functions and intelligence (Kaufman & Kaufman, 2004). In this study, the KBIT was used to control for general differences in intelligence normally seen in a community sample. The KBIT is composed of three subtests that measure verbal and nonverbal (matrices) intelligence. Due to the diversity of the recruitment community in terms of native languages (i.e., diverse cohort of undergraduate and graduate university students), only the matrices subtest of the KBIT was completed by participants. This subtest includes 46 items that assess abstract reasoning. Standard scores in the matrices subtest are age-corrected and go from 40 to 132, with a higher score representing a better ability to solve problems using fluid reasoning and visual processing (Kaufmann & Kaufmann, 2004).

2.2.2.2 Barratt Impulsiveness Scale (BIS-11):

This scale developed by Patton and colleagues (1995) is a 30-item self-report questionnaire widely used in clinical practice to measure trait impulsivity (see Appendix B). The BIS-11 has a good internal consistency (Cronbach’s α of 0.82; Patton et al, 1995). It is based on a three-factor
framework, assessing motor, attention, and non-planning impulsivity. In this study, the BIS-11 is used as a validation tool for eye movements as a measure of trait impulsivity. Responses are scored from 1 (never) to 4 (always). Scores range from 30-120, where higher scores represent higher impulsiveness.

2.2.2.3 Hypomanic Personality Scale (HPS):

The HPS is a 48-item self-report questionnaire developed by Eckblad and Chapman (1986) and included in Appendix C. It has a reliable internal consistency (Cronbach’s α of 0.87; Eckblad & Chapman, 1986) and was designed to identify individuals with a hypomanic personality, which robustly predicts the risk of BD (Kwapil et al., 2000). In this study, the HPS was used to assess participants’ hypomania proneness. Responses are a binary qualitative category (true or false) and scoring of each statement is either 1 or 0. Total scores range from 0 to 48, where higher scores indicate a greater degree of hypomania proneness. During data collection, the HPS was incorrectly administered, omitting the last two items, for the first thirty-six participants. Upon realizing this error, immediate corrective measures were implemented. To rectify the situation, all thirty-six participants were contacted via email and requested to provide responses to the missing two items. Thirty-two of the thirty-six participants promptly responded and completed the additional items via email. The four participants with incomplete HPS were included in further analysis except for the Cronbach’s alpha calculation. The remaining twenty-four participants were administered the full version of the HPS during testing.
2.2.3 Eye movement tasks

2.2.3.1 Apparatus and stimuli:

Participants viewed stimuli on a 53.2 x 29.9 cm LCD VIEWPixx/3D monitor (VPixx Technologies Inc., Saint-Bruno, QC, Canada; 120 Hz; 1920 x 1200 pixels) at a distance of 55 cm in a dimly lit laboratory. Eye movements from the right eye were recorded using a video-based eye tracker (Eyelink 1000 desktop mount; SR Research Ltd, Ottawa, ON, Canada) at a sampling rate of 1000 Hz (yielding 1000 samples of horizontal and vertical eye position per second). Participants were seated comfortably with their head supported by a forehead and chin rest to minimize head movements. All experiments were programmed using MATLAB R2023a (MathWorks Inc., Natick, MA) and Psychtoolbox 3.0.8 (Brainard, 1997; Pelli, 1997). All stimuli were black (luminance 0.109 candela per metre squared [cd/m²]) or white (92.69 cd/m²) presented on a gray background (53.26 cd/m²) for high contrast.

2.2.3.2 Antisaccade task:

Participants completed a pro- and antisaccade task (Munoz and Everling, 2004) with a block design based on the internationally standardized protocol for clinical populations (Antoniades et al., 2013; see Fig. 2.1). The experiment consisted of five blocks in the following sequence: one prosaccade block with 60 trials, three antisaccade blocks with 40 trials each, and one prosaccade block with 60 trials. The eye tracker was calibrated and validated (fixation noise ± 0.5°) using a 9-point grid prior to each block. General experiment instructions were displayed at the beginning.
of the task and subsequently explained to the participant. Trial specific instructions were displayed at the beginning of each block. Before the first prosaccade and antisaccade blocks, participants completed five practice trials to verify that instructions were correctly interpreted. Each trial started by displaying a central fixation target made of a combined shape of a black and white bullseye and crosshair (0.3° and 0.1° radius of the outer and inner circle, respectively), designed to maximize fixational stability (Thaler et al., 2013). The fixation time was randomized for each trial to be any value between 1 to 2 seconds. After fixation there was a gap period with no stimulus displayed for a time of any value between 100-350 milliseconds (ms) calculated randomly for each trial. Lastly, a target (black filled circle, radius 0.3°) was presented in the periphery at 10° horizontally to the left or right of fixation. In the prosaccade task, participants were instructed to look at the target as fast as possible. In the antisaccade task, they were told to look in the opposite direction of the target as fast as possible. The target stimulus remained on the screen for 1000ms before the trial timed out.

2.2.3.3 Sinusoidal smooth pursuit:

Sinusoidal motion is commonly used to characterize the basic oculomotor tracking capabilities of participants, get baseline measures of pursuit, and as a bedside measure of oculomotor function (Leigh and Zee, 2015). The eye tracker was calibrated and validated (fixation noise ± 0.5°) using a 9-point grid prior to each block. General experiment instructions were displayed at the beginning of the experiment and subsequently explained to the participant. In our task (see Fig. 2.1), each trial started with a fixation cross (black, radius 0.25°) in the center of the screen. Participants were instructed to press a button when ready to begin the trial. The pursuit target
was a Gaussian dot (white, radius 0.3°, standard deviation 0.14°) that moved sinusoidally for five cycles along the horizontal meridian with a frequency of 0.24 Hz or 0.40 Hz (i.e., peak speed of 15°/s or 25°/s, respectively) in randomized trial order. Deflection points were at ±10° to the left/right of the center. In our experiment, the sinusoidal pursuit task consisted of one block of ten trials, five at each speed, with five repetitions/deflections; each trial lasted 2.4 or 4.1 s for each speed (25°/s or 15°/s, respectively).

2.2.3.4 Predictive pursuit:

The ability to predict visual target motion during brief disappearance of the moving object is crucial for many tasks. Motion trajectories where the target is occluded and reappears are used to understand these predictive mechanisms using pursuit as a model system (Kowler et al., 2019). In the current study, the predictive pursuit task consisted of two blocks of 40 trials each (see Fig. 2.1). The eye tracker was calibrated and validated (fixation noise ± 0.5°) using a 9-point grid prior to each block. General experiment instructions were displayed at the beginning of the task and subsequently explained to the participant. Each trial started with a fixation cross (black, radius 0.25°) in the center of the screen and participants were instructed to press a button to begin the trial. The target was a gaussian dot (white, radius 0.3°, standard deviation 0.14°). In each trial, the target appeared at 10° to the left of the screen center and then followed a step-ramp trajectory (Rashbass, 1961). The purpose of this procedure is to remove the saccade that is commonly made to initiate pursuit, and instead obtain a clear, saccade-free pursuit onset. Here, the target stepped 2° to the left of the starting point (12° from the center) and then proceeded to move centripetally to the right at a constant velocity of 10°/s. After 800 ms of target motion, the
target disappeared for 800 ms (occlusion) before reappearing and moving for another 800 ms. This procedure resulted in a trajectory duration of 2400 ms. Participants were instructed to closely track the target with their eyes even during the occlusion window of the trajectory.

A.

Figure 2.1. Schematics for eye movement tasks. A. Antisaccade (left) and prosaccade (right) trials. B. Sinusoidal smooth pursuit trial. C. Predictive pursuit trial.
2.2.4 Eye movement data preprocessing

All eye movement data were analyzed in MATLAB R2023a. Eye velocity was derived by differentiating eye position over time. For the pro- and antisaccade tasks, saccades were detected using combined a velocity threshold lambda (= 5), duration (6 ms), and amplitude (>1° for saccades, < 1° for microsaccades) criteria (see Engbert & Mergenthaler, 2006). All trials were manually inspected, and trial exclusion criteria were as follows: blinks during the saccade, incorrectly detected saccades or undetected saccades, and loss of eye tracker signal (4.97% of all trials). Two participants were excluded from analysis of this task, one due to a one antisaccade block not being recorded by the eye tracker, and one due to over 80% error rate in antisaccade trials.

For pursuit analysis, eye movement traces were filtered using a second-order Butterworth filter with cut-off frequencies at 15 Hz (position) and 30 Hz (velocity). Pursuit onset was detected with a piecewise linear function fitted to the position trace (Fooken et al., 2022). Catch-up saccades during pursuit tasks were detected using a velocity criterion where five consecutive frames must exceed a threshold of 20°/s or 30°/s, for target velocities 15°/s or 25°/s, respectively. Onsets and offsets were then determined from acceleration minima and maxima, respectively (Fooken et al., 2022). Additionally, catch-up saccades and blinks were removed from velocity and acceleration data for the analysis of the smooth portion of the pursuit response. All trials were manually inspected, and trial exclusion criteria for pursuit trials were as follows: undetected saccades, blinks during predictive pursuit trials, and eye tracker signal loss (4.58% of all predictive pursuit trials, 0.16% of all sinusoidal pursuit trials). One participant was excluded.
from analysis of both pursuit tasks, due to significant signal loss from the eye tracker on more than 90% of the trials.

2.2.5 Eye movement measures

For all measures, an average value per participant across trials was calculated and within-individual variability was analysed from the standard deviation of the measure across trials. In the antisaccade task, performance was quantified by error rate in antisaccade trials (i.e., number of errors over total number of antisaccade trials). Additionally, saccade latency (time from target onset to saccade onset) was analysed for both pro- and antisaccade trials. Saccades that were initiated during the gap period, herein termed premature saccades, were counted and excluded from the primary analysis. Saccades that happened between 90 ms and 120 ms after cue onset, herein termed express saccades (Fischer & Ramsperger, 1984), were counted. Instances where participants made an incorrect saccade and corrected themselves were counted as errors.

In the sinusoidal pursuit experiment, gain (mean difference between eye and target velocity) was calculated omitting data within 140 ms of the deflection points to account for natural, anticipatory slowing of the eye. Additionally, catch-up saccades that predicted the deflection point, moved ahead along the horizontal and then waited for the target to arrive were observed; these were termed predictive saccades and analysed.

In the predictive pursuit experiment, initial eye acceleration (eye acceleration in the first 100 ms of pursuit) was measured and analysed. Task-specific measures calculated included saccade rate during occlusion (occurrence of a saccade in each timepoint), gain (before, during and after the occlusion window), the latency of the last saccade made during the occlusion time
window relative to the end of the occlusion window, position error at target reappearance, and initial deceleration after occlusion (slope of the velocity profile after occlusion onset).

### 2.2.6 Statistical analyses

The general assumptions for each analysis (e.g., normality, absence of outliers) were validated for all variables of interest. All correlations reported here used the non-parametric Spearman correlation and report the Spearman rho ($\rho$) as well as the classification for effect size for studies on individual differences in psychology (Gignac & Szodorai, 2016). All correlations control for intelligence as measured by the KBIT-2 standard score. A Welch two sample t-test was used to perform mean comparisons for pro- and antisaccade measures and sex comparisons for BIS-11 scores. A Kruskal Wallis non-parametric test was used to perform sex comparisons in HPS scores and oculomotor measures. A two one-sided test (TOST) equivalence test was used on all measures to assess whether the lack of significance in the correlation indicated a lack of relationship between the variables. All statistical analyses were performed using the R Software v 4.3.0.

### 2.3 Results

In this section, we will report the results of investigating the relation between hypomania proneness and impulsivity, as assessed with eye movement tests, validated using an impulsivity self-report questionnaire. This section is organized as follows. First, we will show demographic characteristics for the assessed sample of healthy, young observers. Second, we will summarize
cognitive and impulsivity assessment results as well as hypomania proneness in the current sample of observers. Third, we will show eye movement data, showcasing individual as well as group results, and finally correlations between eye movement measures and hypomania proneness in order to address the main study hypotheses.

2.3.1 Sample characteristics

Table 2.1 summarizes general demographic characteristics and cognitive assessment scores for the tested sample. We tested sixty healthy, young adults, most of which are university students with 16.8 (±2.72) mean years of education. In accordance with their educational background, the mean standardized IQ in this sample was 113.47 (±10.86), which is on the high end of the average scores in the general population (i.e., average scores range from 85 to 115). Our sample had a mean depression score of 6.46 (±3.74), indicating a low presence of depression symptomatology in a depression scale where scores can range from 0 to 60 (a score of 0 indicates no presence of depression symptoms and a score above 16 is considered “at risk” of developing clinical depression); one observer was excluded due to a CESD score >16.
Table 2.1. Demographic characteristics and cognitive assessments scores of participants ($n = 59$).

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>Range $^a$</th>
<th>Cronbach’s $^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.5</td>
<td>4.09</td>
<td>19 – 35</td>
<td></td>
</tr>
<tr>
<td>Sex ($n$ [% female])</td>
<td>40 (67.8%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education (years)</td>
<td>16.8</td>
<td>2.72</td>
<td>12 – 24</td>
<td></td>
</tr>
<tr>
<td>CES-D$^c$ (score)</td>
<td>6.46</td>
<td>3.74</td>
<td>0 – 16</td>
<td>0.53</td>
</tr>
<tr>
<td><strong>KBIT-2 Matrices subtest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw</td>
<td>41.19</td>
<td>3.07</td>
<td>31 – 46</td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td>113.47</td>
<td>10.86</td>
<td>86 – 132</td>
<td></td>
</tr>
<tr>
<td><strong>BIS-11 and subscales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>59.49</td>
<td>10.04</td>
<td>38 – 88</td>
<td>0.57</td>
</tr>
<tr>
<td>Motor</td>
<td>21.51</td>
<td>4.17</td>
<td>13 – 33</td>
<td>0.26</td>
</tr>
<tr>
<td>Attention</td>
<td>16.59</td>
<td>4.18</td>
<td>9 – 28</td>
<td>0.081</td>
</tr>
<tr>
<td>Non-planning</td>
<td>21.24</td>
<td>4.09</td>
<td>14 – 33</td>
<td>0.035</td>
</tr>
<tr>
<td><strong>HPS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14.81</td>
<td>7.93</td>
<td>3 – 37</td>
<td>0.71</td>
</tr>
</tbody>
</table>

$^a$Range of our sample’s distribution.

$^b$Cronbach’s alpha for self-report questionnaires in our sample (see Methods).

$^c$Center for Epidemiologic Studies Depression scale (see Appendix 1) used at screening, scores range from 0 to 60 with a cut-off of over 16 (Radloff, 1977).
Figure 2.2. Distribution of scores on the cognitive assessments implemented in our sample and correlation between them. A. Hypomanic Personality Scale scores. B. Barratt Impulsiveness Scale scores. C. Correlation between BIS-11 and HPS in our sample.
2.3.2 Cognitive assessments

Our sample scored on average 59.49 (±10.04) in the total impulsiveness scale measured by the BIS-11; this score represents a medium to low level of impulsivity. Additionally, these scores concur with values obtained in a large healthy, young population \( (n = 409, M = 63.82, SD = 10.17, \text{ in Patton et al., 1995} \) and \( n = 48, M = 64.79, SD = 10.24, \text{ in Pietrzak et al., 2008} \) and are lower than scores reported for symptomatic BD patients \( (M = 75.1, SD = 8.1, \text{ in Nandagopal et al., 2011}) \). We therefore consider our sample average in terms of impulsivity. Of note, the range of values (Table 2.1) indicates that some of our participants \( (n = 4) \) fall above the mean observed in the previously cited clinical study. These participants have higher levels of impulsiveness than the average of a young population. Similarly, some of our participants show low levels of impulsivity with scores beneath 1 SD of our mean. Importantly, as expected, impulsivity in our sample positively correlated with hypomanic personality \( (\rho = 0.31, p = 0.02; \text{ Fig. 2.2}) \), indicating that higher proneness to hypomania goes with higher levels of impulsivity in our healthy sample.

We next analyzed sex differences and intelligence as possible confounding variables, as has been previously found in the literature (Aichert et al., 2012). We did not find sex differences in BIS-11 scores \( (t(53.8) = -0.29, p = 0.77) \) and we found no correlation between BIS-11 and standardized IQ \( (\text{Pearson’s } r = 0.1, p = 0.51) \). Moreover, we calculated the Cronbach’s alpha for all scales, our sample showed unacceptable internal consistencies \( (\alpha < 0.5) \) for the BIS-11 subscales. Hence, we did not perform any further analysis with subscale scores.

Furthermore, we show an average score of 14.81 (±7.93) in hypomania proneness measured by the HPS. This value is aligned to results obtained in a healthy, young sample with
low hypomania proneness \((n = 1,519, \text{ Eckblad & Chapman, 1896})\) and is lower than scores in BD patients \((\text{e.g., Kwapil et al., 2000})\). Akin to these studies, we did not find sex differences in hypomania proneness \((\chi^2(1) = 2.1, p = 0.15)\) and no correlation to standardized IQ \((\rho = 0.02, p = 0.90)\). Importantly, we did not find sex differences with any of the eye movement measures showed in this work \((p > 0.3 \text{ for all measures})\).

### 2.3.3 Antisaccade task performance and relation to hypomania proneness

A total of 6,840 prosaccade trials and an equal number of antisaccade trials were recorded in 57 observers \((n = 2 \text{ were excluded, as reported in Methods above, one of them had a } >80\% \text{ error rate in antisaccade trials, which is significantly higher than the average error rate of } \sim20\% \text{ in healthy observers; Hutton & Ettinger, 2006})\). Figure 2.3 shows four typical examples of trials from one representative observer with an accurate prosaccade (Fig. 2.3A), an accurate antisaccade (Fig. 2.3B), a change of mind after an antisaccade error (Fig. 2.3C), and an express saccade (Fig. 2.3D).
Figure 2.3. Example traces for trials with a correct prosaccade (A), correct antisaccade (B), incorrect antisaccade where participant corrected themselves (C), and an express saccade (D). Dashed line: gap onset, blue line: target onset, green line: target location.

Figure 2.4. Prosaccade (A) and antisaccade (B) latency distributions.
Mean antisaccade latency, error rate and number of express saccades and their relationship with hypomania proneness and impulsivity are summarized in Table 2.2. On average, saccade latencies in prosaccade trials (Fig. 2.4, $M = 159.8$, $SD = 28.23$) were significantly lower than in antisaccade trials (Table 2.2; $M = 227.4$, $SD = 31.9$, $[t (110) = -11.68, p < 0.001]$). These results reflect the challenging nature of the antisaccade task, which requires the programming of a reflexive, visually guided saccade, its subsequent inhibition, followed by the execution of a voluntary saccade in the opposite direction. Congruently, the error rate in antisaccade trials was significantly higher than in prosaccade trials [$W = 48, p < 0.001$].

**Table 2.2.** Descriptive statistics and correlations with HPS and BIS-11 scores for antisaccade performance.

<table>
<thead>
<tr>
<th>Measure</th>
<th>$M$</th>
<th>$SD$</th>
<th>HPS</th>
<th>BIS-11</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>rho</td>
<td>$p$</td>
</tr>
<tr>
<td>Error rate</td>
<td>0.17</td>
<td>0.13</td>
<td>0.15</td>
<td>0.26</td>
</tr>
<tr>
<td>Prosaccade latency (ms; $n = 57$)</td>
<td>159.8</td>
<td>28.2</td>
<td>-0.082</td>
<td>0.54</td>
</tr>
<tr>
<td>Antisaccade latency (ms; $n = 57$)</td>
<td>227.4</td>
<td>31.9</td>
<td>-0.17</td>
<td>0.2</td>
</tr>
<tr>
<td>Express saccades (mean number; $n = 55^*$)</td>
<td>6.54</td>
<td>6.87</td>
<td>0.26</td>
<td>0.06</td>
</tr>
</tbody>
</table>

* Two outliers were detected using the Rosner test and excluded from analysis of express saccades.

We expected to see a positive relationship between the antisaccade error rate and hypomania proneness. Analysis of antisaccade performance related to HPS revealed there is not a monotonic statistical relationship between error rate and hypomania proneness ($\rho = 0.15, p = 0.25$; Fig 2.5A); the relationship found is of a small effect and is consistent with the literature.
(Aichert et al., 2012). Similarly, no relationship was found between the latency of visually guided saccades (i.e., prosaccades) with HPS score ($\rho = -0.082$, $p = 0.54$). We next investigated express saccades—saccades made within 90 and 120 ms of target onset—which showed a positive trend with hypomania proneness ($\rho = 0.26$, $p = 0.06$; Fig 2.5B), with a medium effect size.

**A.**

**B.**

**Figure 2.5.** Correlations between hypomania proneness and antisaccade performance. **A.** performance measured as error rate in antisaccade trials. **B.** mean number of express saccades during antisaccade trials.

### 2.3.4 Sinusoidal smooth pursuit

A total of 580 sinusoidal smooth pursuit trials were recorded from 58 observers ($n = 1$ was excluded, see Methods). **Figure 2.6** shows example position and velocity traces from one representative participant. In general, participants were able to track the sinusoidal target motion
smoothly (black line in Fig. 2.6) with an average gain of 0.95 (Table 2.3), indicating excellent velocity matching of the eye to the target. Sinusoidal smooth pursuit performance and the relationship between pursuit metrics and hypomania proneness and impulsivity are summarized in Table 2.3.

**Figure 2.6.** Example position (top) and velocity (bottom) traces for a sinusoidal pursuit trial.

Bold squares show predictive saccades at the moment of deflection. Black line: eye position/velocity, red line: target position/velocity, green stars: saccade onsets, blue stars: saccade offsets.

**Table 2.3.** Descriptive statistics and correlations with HPS and BIS-11 scores with sinusoidal smooth pursuit measures.

<table>
<thead>
<tr>
<th>Measure</th>
<th>M</th>
<th>SD</th>
<th>HPS rho</th>
<th>HPS p</th>
<th>BIS-11 rho</th>
<th>BIS-11 p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain ($n = 58$)</td>
<td>0.95</td>
<td>0.07</td>
<td>-0.16</td>
<td>0.21</td>
<td>-0.08</td>
<td>0.52</td>
</tr>
<tr>
<td>Predictive saccades (mean number; $n = 58$)</td>
<td>1.74</td>
<td>1.32</td>
<td>0.21</td>
<td>0.11</td>
<td>0.13</td>
<td>0.32</td>
</tr>
</tbody>
</table>
We expected a negative relationship between gain and hypomania proneness. Analysis of the relationship between velocity gain as a smooth pursuit quality marker with hypomania proneness shows a negative non-significant relationship of small effect size ($\rho = -0.16, p = 0.21$; Fig. 2.7A) and no relation with impulsiveness ($\rho = -0.08, p = 0.52$). We observed predictive saccades near the deflection points of the sinusoidal trajectory (see bolded squares, Fig. 2.6 top). These saccades shift gaze towards a future location of the target trajectory. We analyzed this behaviour and found no correlations but a small effect size of rho between the mean number of predictive saccades and both hypomania proneness ($\rho = 0.21, p = 0.11$; see Fig. 2.7B) and impulsiveness ($\rho = 0.13, p = 0.32$).

**Figure 2.7.** Correlations between gain (A) and mean number of predictive saccades (B) with hypomania proneness.
2.3.5 Predictive pursuit

A total of 2,320 predictive pursuit trials were recorded from 58 participants ($n = 1$ excluded, see Methods). Figure 2.8 shows example position and velocity traces from a representative participant. Here we can see the ramp created by the target trajectory (red dotted line), and the close tracking of it with the eye (black line). Statistics for predictive pursuit measures and their relationship with hypomania proneness are summarized in Table 2.4.

![Figure 2.8](image)

**Figure 2.8.** Example position (top) and velocity (bottom) traces for predictive pursuit trial. Black line: eye position/velocity, red line: target position/velocity, green stars: saccade onsets, blue stars: saccade offsets.
Table 2.4. Descriptive statistics and correlations with HPS and BIS-11 scores with predictive pursuit measures.

<table>
<thead>
<tr>
<th>Measure</th>
<th>M</th>
<th>SD</th>
<th>HPS</th>
<th>BIS-11</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>rho</td>
<td>p</td>
</tr>
<tr>
<td>Initial eye acceleration (°/ms², n = 58)</td>
<td>47.6</td>
<td>13.1</td>
<td>-0.24</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.14</td>
<td>0.29</td>
</tr>
<tr>
<td>Deceleration (°/ms², n = 57)</td>
<td>-34.9</td>
<td>10.3</td>
<td>0.26</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.14</td>
<td>0.3</td>
</tr>
<tr>
<td>Anticipatory saccade latency (ms, n = 58)</td>
<td>357.9</td>
<td>70.7</td>
<td>0.2</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.01</td>
<td>0.99</td>
</tr>
<tr>
<td>Accuracy (°, n = 58)</td>
<td>-0.32</td>
<td>1.78</td>
<td>0.12</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.26</td>
<td>0.05</td>
</tr>
</tbody>
</table>

An outlier was detected using the Rosner test and excluded from analysis of deceleration measurements.

Participants initiated pursuit and smoothly tracked the target while it was visible. Observers then continued to pursue the target briefly after occlusion onset and then there was a characteristic drop in eye velocity (M = 179.6 ms after occlusion onset, SD = 26.82) as can be seen in Fig. 2.9A, that shows individual means of eye velocity (green traces) and the sample mean (black line). Typically, anticipatory eye acceleration can be seen before target reappearance after the occlusion window (Bennett & Barnes, 2004). However, our data shows no anticipatory acceleration (see Fig. 2.9B) but instead reveals that participants generally saccade close to the predicted location of target reappearance during the occlusion window.
Figure 2.9. A. Individual (green lines) and group (black line) mean eye velocity around occlusion. B. Individual (green lines) and group (black line) mean eye acceleration around occlusion. C. Individual (green lines) and group (black line) mean saccade rate during occlusion.
We expected to see a negative relationship between initial eye acceleration and hypomania proneness, akin to this hypothesis we show a small effect size negative trend between these measures ($\rho = -0.24, p = 0.06$; see Fig. 2.10A) but only a non-significant small effect size with impulsiveness ($\rho = -0.14, p = 0.29$). Analysis revealed a positive trend in the correlation between deceleration after occlusion onset and hypomania proneness ($\rho = 0.26, p = 0.06$; see Fig. 2.10B), again not present when correlated with impulsiveness ($\rho = 0.14, p = 0.3$).

Deceleration analysis revealed one outlier for this measure and this data point was removed from the analysis (Grubbs test $p < 0.01$). Moreover, analysis of the anticipatory saccades that happen close to reappearance revealed two peaks of saccade occurrence in the occlusion window, one at the beginning of the occlusion and one right before target reappearance (see Fig. 2.9C). We quantified this behaviour by calculating the latency of the last anticipatory saccade during occlusion relative to target reappearance for each trial. We then averaged these latencies for each participant and correlated them with hypomania proneness and we found a non-significant medium effect sized relationship ($\rho = 0.20, p = 0.13$; see Fig. 2.10C).
Figure 2.10. Correlations between initial eye acceleration (A), deceleration during 100ms to 300ms after occlusion onset (B), and latency of the last saccade during occlusion relative to target reappearance (C).

Finally, due to the lack of significance of our results we performed an equivalence test (TOST). With symmetrical equivalence bounds of 0.3, the test revealed that our effect size ($\rho$) is not equivalent and not statistically different from zero ($t(-1.16); p = 0.12$) for all of our measures.
Chapter 3: Discussion

Increased impulsivity is a core feature of bipolar disorder (BD). This study aimed to investigate whether eye movements relate to impulse control performance and proneness to hypomania in a cohort of young adults, not diagnosed with any mood disorder. We assessed cognitive executive function by applying the Hypomanic Personality Scale (Eckblad & Chapman, 1986) as a measure of hypomania proneness and the BIS-11 (Patton et al., 1995) as a measure of trait impulsivity. We then implemented a battery of eye movement tasks to measure inhibitory (i.e., the antisaccade task) and predictive or anticipatory (i.e., smooth pursuit tasks) mechanisms and correlated the performance in these behavioural tasks to the cognitive measures. Failure to inhibit inappropriate actions and inability to predict or anticipate consequential events are both fundamental features of the impulsivity construct (Whiteside & Lynam, 2001) and are a feature of mania in BD (Grande et al., 2015). Overall, the results reported here reveal small effect non-statistically significant correlations between eye movement metrics and both hypomania proneness and trait impulsivity. These small to medium effect sizes reflect trends in the expected direction and are consistent with findings in the literature (Aichert et al., 2012).

3.1.1 Response inhibition

Our results show a positive small effect sized trend between antisaccade error rate and hypomania proneness. These results suggest that people with a higher degree of hypomania proneness fail to inhibit a reflexive oculomotor movement more than observers with low hypomania proneness. These findings are congruent with literature showing that BD patients
have significantly higher error rates in this task when compared to healthy controls (Reilly et al., 2014; Tien et al., 1996; Yep et al., 2018). Moreover, cognitive impairments in both the Stop-Signal Task (Bourne et al., 2013; Thaker, 2007) and antisaccade task (i.e., increased antisaccade error rate; Reilly et al., 2014) have also been identified in first-degree, undiagnosed relatives of patients with BD.

Moreover, we found no correlation between prosaccade latency and hypomania proneness, consistent with literature showing no differences in visually guided saccade latency between BD patients, other mood disorder patients, and healthy controls (Harris et al., 2009). This suggests the saccade initiation mechanism might be unaffected by hypomania proneness, and symptomatic BD. These results are in agreement with previous studies in schizophrenia patients (an illness closely related to BD) that reflect deficits in inhibition of reflexive saccades but not in saccade initiation (Barton et al., 2008). Finally, our finding of a positive trend of medium effect size between the mean number of express saccades and hypomania proneness is coherent with literature on saccade performance in psychiatric populations, that found increased express saccade rate in attention deficit hyperactivity disorder (ADHD) and BD patients (Yep et al., 2018).

3.1.2 Prediction and anticipation

Regarding to smooth pursuit tasks, we did not find a relationship between smooth pursuit gain and hypomania proneness or impulsivity. This is not consistent with studies that show decreased pursuit quality in BD patients relative to controls (Brakemeier et al., 2020; Kathmann et al., 2003; Lencer et al., 2017; Sweeney et al., 1999). These results may indicate that deficits in
the brain networks controlling the gain in smooth pursuit behaviour are not related to hypomania proneness in the context of BD symptomatology, but may be related to other factors of the illness such as psychosis (Brakemeier et al., 2020; Lencer et al., 2015). In contrast, we observed a negative trend of medium effect size between initial eye acceleration and hypomania proneness, indicating potential impairments in the initiation phase of the pursuit eye movement. Consistent with this finding, literature shows decreased initial eye acceleration in BD patients relative to healthy controls (Lencer et al., 2017). This deficit suggests impairments in the use of early visual motion information to drive sensorimotor motion responses (i.e., the pursuit eye movement).

On the one hand, we show a positive trend between deceleration (i.e., negative acceleration) and hypomania proneness, suggesting people with higher degree of hypomania take longer to decrease eye velocity after occlusion. These results are consistent with previous work showing BD patients use predictive mechanisms to sustain pursuit after target extinction longer than healthy controls (Trillenberg et al., 1998, 2017). On the other hand, there is no relationship between hypomania proneness and anticipatory saccade latency relative to target reappearance. This is in contrast to findings of significantly decreased anticipatory pursuit in impulsive individuals relative to non-impulsive participants (Cirilli et al., 2011). However, anticipation and redirection of gaze to a predicted location seem to support the notion of hypomania being defined by increased goal-directed activity (APA, 2013).

It is important to mention the absence of practice trials with a completely visible target trajectory in our experimental setup. The lack of trials showing the full trajectory may be a contributing factor to the observed absence of anticipatory eye acceleration at the end of the occlusion window. Bennett & Barnes (2003, 2004) used a randomized combination of trials that included full ramps and different occlusion durations. They highlight the presence of anticipatory
acceleration before target reappearance. However, it is noteworthy that these studies had a small sample size (n = 9; n = 8) of only or mostly observers experienced in oculomotor experiments and only individual traces are shown. Authors also report a lack of anticipatory increase in velocity prior to target reappearance in some participants. Potential training effects could be a confound for participants who randomly observed full ramps before occlusion trials. Relevant to this, Madelain & Krauzlis (2003) research showed that with repeated training in occlusion paradigms, including full ramp control trials, learning significantly increases eye velocity during occlusion compared to baseline.

3.1.3 Neural substrates

The neural substrate of the antisaccade task oversees two separate processes, the inhibition of a preplanned motor command and the planning and execution of an opposite volitional response. The inhibition of the reflexive saccade relies on connections between the dorsolateral prefrontal cortex and saccade generation areas like the FEF, SEF, and SC (Munoz and Everling, 2004). The LIP is then thought to mediate the calculation of the appropriate saccade location (i.e., opposite to the actual visual stimuli) and signal the appropriate areas for the initiation of the movement (Zhang & Barash, 2004). Top-down connectivity with the SC affect this inhibitory function and may be affected in BD (Huang et al., 2022).

Smooth pursuit eye movements comprise crucial predictive mechanisms that allow for an accurate tracking of target motion (Kowler et al., 2019). These predictive mechanisms likely arise in frontal cortical eye movement areas FEF and SEF (de Hemptinne et al., 2008; Missal & Heinen, 2001, 2004; Schall, 2015). Similarly, evidence shows impaired anticipatory and
predictive pursuit following FEF lesions (MacAvoy et al., 1991). In parallel, BD patients show abnormal functional connectivity in the sensorimotor network between the superior frontal gyrus and both the medial frontal gyrus and the right supplementary motor area (Khadka et al., 2013). Additionally, reduced inferior frontal gyrus activation during response inhibition tasks was observed in young participants at high genetic risk of BD (Roberts et al., 2013). Given the FEF and SEF are located within these regions of the sensorimotor network, this may be a neural correlate underlying the prediction and anticipation differences in this population.

3.1.4 Limitations

The present work has limitations that must be considered when interpreting the data. First, the magnitude of the effect sizes reported here points to a sample size constraint. Literature review on behavioral correlates of impulsivity (i.e., prepotent response inhibition) show sample sizes of over 300 participants and report comparable, but statistically significant, effect sizes as the ones reported in this thesis. For example, Aichert and colleagues (2012) tested \( n = 504 \) healthy participants in four prepotent response inhibition tasks (antisaccade task, Stroop task, Stop-Signal task, and Go/No-Go task), correlated the performance with impulsiveness scores in the BIS-11 and found a positive relationship with antisaccade error rate (Pearson’s \( r = 0.164, p < .001 \)). A post hoc power analysis for the present study shows that a sample size of 164 observers would have been necessary to achieve statistical significance given the small effect sizes obtained here to achieve 0.95 power. Due to feasibility considerations in the methodological planning of this thesis, it was decided to aim for a sample of 60 participants to obtain a wide
distribution of HPS scores. This sample size is consistent with previous studies in hypomania proneness, which ranged from samples of $n = 24$ to $n = 66$ (Gruber et al., 2021; Damme et al., 2017; Mason et al., 2012; O'Sullivan et al., 2011). Notwithstanding the small effect sizes, a coherent pattern of results emerged, where antisaccade error rate, express saccades, pursuit initial eye acceleration, and deceleration were related to hypomania proneness, and the direction of these relationships is consistent with the literature. An equivalence test showed that the effect sizes for all our measures are not equivalent and not statistically different from zero. This undetermined result shows that for effect sized up to 0.3 it is not possible to state that an effect does not exist. These results show that, consistent with the literature, our effects would remain and turn significant with a higher sample size.

Additionally, although research focusing on premorbid characteristics offers great advantages it comes with an important limitation. As can be seen on our distributions for both HPS and BIS-11 scores, our population reflected a healthy cohort. We did not have many participants with unusually high HPS or BIS-11 scores, that would be treated as risk factors, and this may have prevented us from observing stronger effects. A previous screening process for further studies looking to draw conclusions on the trait vs state components of impulsivity debacle is important to guarantee a wider distribution of scores.

To our knowledge, very few studies in the literature look into smooth pursuit measures as a behavioural proxy for impulsivity. Our study has the novelty of describing possible biomarkers for more objective measures of this construct in relation to the bipolar spectrum. However, this exploratory nature suffers from an uncertainty at the moment of interpreting the results. The lack of information in the literature prevents us from comparing our results or validating our
measures. Importantly, research on individual differences in oculomotor function shows that all of the measures used in this study have a very good reliability (Bargary et al., 2017). This study also shows significant sex differences in many oculomotor measures; however, we did not find sex differences in our sample. Future studies could use this test retest approach to report the reliability of our oculomotor measures in relation to impulsiveness and also assess the validity with comparable, more established behavioral assessments of impulsivity.

Moreover, by not including practice trials involving the complete ramp in the predictive pursuit task of our study, we may have failed to allow the generation of the predictive mechanisms that allow for anticipatory pursuit. However, studies on the occlusion paradigm do not show definitive evidence for the occurrence of anticipatory pursuit prior to target reappearance (Bennett & Barnes, 2003, 2004; Churchland et al., 2003; Portron & Lorenceau, 2017). At this point it becomes relevant to highlight that studies on anticipatory pursuit using a transiently disappearing target are not homogeneous in task or stimulus choice.

Nonetheless, our study shines light on two important aspects of using behavioural measures to assess for complex construct such as impulsivity or prediction in relation a psychiatric disorder. First, the sample size needed to observe statistical significance in the association between behavioral measures and cognitive constructs like impulsiveness or hypomania proneness. Second, the effects of task design and stimulus choice in the interpretation of the obtained responses and further associations made from these results. Both of these aspects highlight the importance of exhaustively understanding the mechanisms each task measures and standardizing these paradigms to allow for more homogeneous comparisons between studies. Here we use the internationally standardized antisaccade task, but there is an imperative need for comparable standardizations in predictive smooth pursuit paradigms.
3.2 Conclusion and significance

In sum, impulsivity is the core feature of BD and the main agent of the detrimental consequences of this condition. Our research contributes modest evidence to the literature on impulsivity and hypomania proneness in the bipolar disorder field. Given the limitations of this study our results pooled together do not allow us to give a definitive answer to the ever-present debate of a trait vs. state nature of impulsivity in BD. However, the trends we show on the relationship between hypomania proneness and eye movement measurements, paired with their similarity to literature on these measures in diagnosed BD patients, would potentially point towards a trait, rather than a state, component of impulsivity in this context.

Our study is the first one to investigate eye movement measures (that have previously been studied in the BD population) in cohort of healthy participants whilst assessing hypomania proneness as a proxy for the risk of developing BD. We additionally address predictive saccades in naturally occurring pursuit eye movements as a potential marker of impulsive tendencies.

To conclude, eye movements are a sensitive, inexpensive, and reliable tool to measure cognitive function. Validating eye movement measures as the ones described in this thesis and their relationship to impulsivity and hypomania proneness could lead to their use in the assessment of treatment efficacy and disease progression.

3.3 Future directions

The contribution of impulsivity to BD and its dissociation in state vs trait components remain uncertain. Future studies using behavioural measures to look into impulsivity and hypomania
proneness need to address several methodological notions. First, a large sample size is needed to achieve a reliable statistical power. Second, the use of standardized tasks to allow for comprehensive comparison with different populations and studies. Additionally, to strengthen future investigations in the predictive and anticipatory smooth pursuit field, we recommend a study that incorporates different stimulus and task variations of the occlusion paradigm in a cohort of naïve, healthy observers. This will allow to reliably address stimulus, task, and training effects in the occurrence of anticipatory acceleration prior to target reappearance during occlusion. Finally, the field needs new behavioural paradigms to explore the impulsivity construct. Attentional tasks could be better suited for this aim, such as a sustained fixation task in a dynamic environment, where we see the effect of distractions during the task and how this relates to impulsiveness constructs.
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Appendices

Appendix A  Center for Epidemiologic Studies Depression Scale

This scale was conducted as an interview with each participant. Following are the instructions for the participant, and the questions that were asked.

Instructions: Below is a list of the ways you might have felt or behaved. Please tell me how often you have felt this way during the past week.

- Rarely or None of the time (Less than 1 day)
- Some or a little of the time (1-2 days)
- Occasionally or a moderate amount of time (3-4 days)
- Most or all of the time (5-7 days)

During the past week:

1. I was bothered by things that usually don’t bother me.
2. I did not feel like eating; my appetite was poor.
3. I felt that I could not shake off the blues even with help from my family or friends.
4. I felt that I was just as good as other people.
5. I had trouble keeping my mind on what I was doing.
6. I felt depressed.
7. I felt that everything I did was an effort.
8. I felt hopeful about the future.
9. I thought my life had been a failure.
10. I felt fearful.
11. My sleep was restless.
12. I was happy.
13. I talked less than usual.
15. People were unfriendly.
16. I enjoyed life.
17. I had crying spells.
18. I felt sad.
19. I felt that people dislike me.
20. I could not get “going”.
A.1 CES-D Scoring

In scoring the CES-D, a value of 0, 1, 2 or 3 is assigned to a response depending upon whether the item is worded positively or negatively.

For items 1-3, 5-7, 9-11, 13-15, 17-20 the scoring is:
• Rarely or none of the time (less than one day) = 0
• Some or a little of the time (1-2 days) = 1
• Occasionally or a moderate amount of time (3-4 days) = 2
• Most or all of the time (5-7 days) = 3

Items 4, 8, 12, 16 are reverse scored as follows:
• Most or all of the time (5-7 days) = 0
• Occasionally or a moderate amount of time (3-4 days) = 1
• Some or a little of the time (1-2 days) = 2
• Rarely or none of the time (less than 1 day) = 3

Possible range of scores is 0 to 60, with the higher scores indicating the presence of more symptomatology.
Appendix B  Barratt Impulsiveness Scale 11 Ed.

<table>
<thead>
<tr>
<th></th>
<th>Rarely/Never</th>
<th>Occasionally</th>
<th>Often</th>
<th>Almost Always/Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I plan tasks carefully.</td>
<td></td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>2</td>
<td>I do things without thinking.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>3</td>
<td>I make-up my mind quickly.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>4</td>
<td>I am happy-go-lucky.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>5</td>
<td>I don’t “pay attention.”</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>6</td>
<td>I have “racing” thoughts.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>7</td>
<td>I plan trips well ahead of time.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>8</td>
<td>I am self controlled.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>9</td>
<td>I concentrate easily.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>10</td>
<td>I save regularly.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>11</td>
<td>I “squirm” at plays or lectures.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>12</td>
<td>I am a careful thinker.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>13</td>
<td>I plan for job security.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>14</td>
<td>I say things without thinking.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>15</td>
<td>I like to think about complex problems.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>16</td>
<td>I change jobs.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>17</td>
<td>I act “on impulse.”</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>18</td>
<td>I get easily bored when solving thought problems.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>19</td>
<td>I act on the spur of the moment.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>20</td>
<td>I am a steady thinker.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>21</td>
<td>I change residences.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>22</td>
<td>I buy things on impulse.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>23</td>
<td>I can only think about one thing at a time.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>24</td>
<td>I change hobbies.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>25</td>
<td>I spend or charge more than I earn.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>26</td>
<td>I often have extraneous thoughts when thinking.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>27</td>
<td>I am more interested in the present than the future.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>28</td>
<td>I am restless at the theater or lectures.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>29</td>
<td>I like puzzles.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>30</td>
<td>I am future oriented.</td>
<td>1</td>
<td></td>
<td>1 2 3 4</td>
</tr>
</tbody>
</table>

B.1 BIS-11 Scoring

In scoring the BIS-11, a value of 1, 2, 3 or 4 is assigned to a response as shown in the scale. Items 1, 7, 8, 9, 10, 12, 13, 15, 20, 29, and 20 are scored in reverse. Total score is the sum of the values.

Each subscale takes different items into consideration, as follows:

Motor: 2, 3, 4, 16, 17, 19, 21, 22, 23, 25, and 30.

Attention: 5, 6, 9, 11, 20, 24, 26, and 28.

Non-planning: 1, 7, 8, 10, 12, 13, 14, 15, 18, 27, and 29.
Appendix C  Hypomanic Personality Scale

The following questions are meant to measure personality traits.

Please indicate with a True or False whether each of the statements below apply to you.

<table>
<thead>
<tr>
<th></th>
<th>True</th>
<th>False</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I consider myself to be pretty much an average kind of person.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>2. It would make me nervous to play the clown in front of other people.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>3. I am frequently so “hyper” that my friends kiddingly ask me what drug I’m taking.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>4. I think I would make a good nightclub comedian.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>5. Sometimes ideas and insights come to me so fast that I cannot express them all.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>6. When with groups of people, I usually prefer to let someone else be the center of attention.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>7. In unfamiliar surroundings, I am often so assertive and sociable I surprise myself.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>8. There are often times when I am so restless that it is impossible for me to sit still.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>9. Many people consider me to be amusing but kind of eccentric.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>10. When I feel an emotion, I usually feel it with extreme intensity.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>11. I am frequently in such high spirits that I can’t concentrate on any one thing for too long.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>12. I sometimes have felt that nothing can happen to me until I do what I am meant to do in life.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>13. People often come to me when they need a clever idea.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>14. I am no more self-aware than the majority of people.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>15. I often feel excited and happy for no apparent reason.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>16. I can’t imagine that anyone would ever write a book about my life.</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>17. I am usually in an average sort of mood, not too high and not too low.</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>
18. I often have moods where I feel so energetic and optimistic that I feel I could outperform almost anyone at anything.

19. I have such a wide range of interests that I often don’t know what to do next.

20. There have often been times when I had such an excess of energy that I felt little need to sleep at night.

21. My moods do not seem to fluctuate any more than most people’s do.

22. I very frequently get into moods where I wish I could be everywhere and do everything at once.

23. I expect that someday I will succeed in several different professions.

24. When I feel very excited and happy, I almost always know the reason why.

25. When I go to a gathering where I don’t know anyone, it usually takes me a while to feel comfortable.

26. I think I would make a good actor because I can play many roles convincingly.

27. I like to have others think of me as a normal kind of person.

28. I frequently write down the thoughts and insights that come to me when I am thinking especially creatively.

29. I have often persuaded groups of friends to do something really adventurous or crazy.

30. I would really enjoy being a politician and hitting the campaign trail.

31. I can usually slow myself down when I want to.

32. I am considered to be kind of a “hyper” person.

33. I often get so happy and energetic that I am almost giddy.

34. There are so many fields I could succeed in that it seems a shame to have to pick one.

35. I often get into moods where I feel like many of the rules of life don’t apply to me.

36. I find it easy to get others to become sexually interested in me.

37. I seem to be a person whose mood goes up and down easily.

38. I frequently find that my thoughts are racing.

39. I am so good at controlling others that it sometimes scares me.
40. At social gatherings, I am usually the “life of the party”.
41. I do most of my best work during brief periods of intense inspiration.
42. I seem to have an uncommon ability to persuade and inspire others.
43. I have often been so excited about an involving project that I didn’t care about eating or sleeping.
44. I frequently get into moods where I feel very speeded-up and irritable.
45. I have often felt happy and irritable at the same time.
46. I often get into excited moods where it’s almost impossible for me to stop talking.
47. I would rather be an ordinary success in life than a spectacular failure.
48. A hundred years after I’m dead, my achievements will probably have been forgotten.
C.1  **HPS Scoring**

In the HPS each item is given a value of 0 or 1 depending on the phrasing of the statement.

Total score is a sum of the values. The following answers are scored as 1:

1. F   17. F   33. T
2. F   18. T   34. T
3. T   19. T   35. T
4. T   20. T   36. T
5. T   21. F   37. T
6. F   22. T   38. T
8. T   24. F   40. T
9. T   25. F   41. T
10. T  26. T   42. T
11. T  27. F   43. T
12. T  28. T   44. T
13. T  29. T   45. T
14. F  30. T   46. T
15. T  31. F   47. F
16. F  32. T   48. F