

Emotion Dynamics of Solitude: How Spending Time Alone Affects the Way We Experience and
Manage Affect

by

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Abstract

Whether we are meeting friends or scrolling through social media, we spend most of our time entrenched in social activity. This is not surprising, as people tend to be happier when they are with others. But is it possible that spending time alone can also make us feel better in some situations? The goal of this dissertation is to explore how solitude affects the way we experience and regulate emotions in daily life. Through the lens of emotion dynamics, solitude is conceptualized as a context in which emotions are deactivated, such that solitude helps reduce heightened emotional arousal (e.g., stress, excitement). However, the effects of solitude on emotions may be different depending on how one spends their time alone and their dispositions toward solitude. This dissertation research uses a Bayesian approach to explore the situational and individual factors that underlie the emotion dynamics of solitude. Study 1 examined the relation between solitude and change in emotions over the course of a negative event. Study 2 examined how solitary activities modulate the relation between solitude and emotion. Finally, Study 3 uses an experience sampling paradigm to examine how solitude predicts emotion regulation strategy choice and effectiveness. Results are integrated into a larger contextual model that provides a deeper understanding of the complex relations between solitude and well-being.

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Introduction

People spend a great deal of time alone. It is estimated that somewhere around 25 to 33 percent of waking time is spent in solitude (Archbell et al., 2020; Larson et al., 1982). But whether solitude is good for people's well-being is a polarizing issue. For instance, there is a prevailing notion that being alone is harmful and should be avoided. From young children incurring solitary timeouts as punishment, to prisoners being forced into solitary confinement for misbehaviour, solitude is often presented as an undesirable, even punitive, state.

Diverse scientific perspectives (e.g., evolution, sociology, anthropology, economics) have espoused the idea that solitude runs counter to the pursuit of happiness and productivity (e.g., Coleman, 2013). For instance, evolutionary biologists argue that the success of humans as a species is largely attributable to our communication and cooperation skills (Tooby & Cosmides, 1996), leading some to conclude that humans are distinctly *ultrasocial* compared to other species (Campbell, 1983). Insights from Game Theory and behavioural economics all suggest that cooperation is more advantageous than going it alone when we want to maximize resources (Yoshida et al., 2008). Even neurological studies suggest that our brains are more "at rest" when we are in the company of others (Coan et al., 2006).

Psychological research also lends credence to the view of solitude as costly for people's well-being. Spending time alone appears to be less rewarding compared to spending time with friends or even strangers (Epley & Schroeder, 2014). It is argued that humans have an innate need to be around others (Baumeister & Leary, 1995), and social isolation triggers feelings of loneliness (Hawkey & Cacioppo, 2010; Qualter et al., 2015). The pursuit of extreme social isolation is associated with a panoply of negative outcomes, including chronic stress, depression, and physical ailments such as cardiovascular disease and immunosuppression (Valtorta et al.,

2018; Williams & Nida, 2011). Indeed, chronic loneliness is decried as a public health issue, which has prompted governmental action in countries such as Great Britain to appoint a “Minister for Loneliness” (Jo Cox Commission on Loneliness, 2017).

In contrast, solitude is only occasionally depicted as relaxing and restorative – a means of escaping the vicissitudes of daily life. Perhaps this evokes an image of standing alone atop a mountain overlooking a forest vista. There is an indelible romanticism in the idea of ‘getting away from it all’ captured in the writing of Thoreau (*Walden*, 1854) and in children’s novels such as *My Side of the Mountain* (George, 1959) and *The Secret Garden* (Burnett, 1911). Solitude is also depicted as a boon for creativity and productivity. Historical accounts often portray (perhaps apocryphally) notable writers, artists, and scientists as sequestering themselves to create masterpieces or discover scientific breakthroughs (France, 1996; Merton, 1958).

These anecdotes aside, there is emerging psychological evidence to suggest that spending some time alone has positive implications for people’s well-being. For example, people may resort to solitude to cope with and recover from the slings and arrows of daily life (Nguyen et al., 2018). This is further exemplified in a survey of over 23,000 people across 134 countries, which ranked ‘being alone’ as the third most *restful* activity, only below reading and being in nature, which are also typical solitary activities (Hammond & Lewis, 2016). Even on social media, when people tweet with the word *solitude*, they tend to include words that evoke a calmer, more positive sentiment (Hipson, Kiritchenko, et al., 2021). Thus, it seems that the idea of being alone to rest and relax has achieved considerable popularity as well.

These contradictory arguments make up the *paradox of solitude* (Galanaki et al., 2015; Larson, 1997), which is the notion that although solitude is believed to enhance some aspects of well-being, it is often experienced as unpleasant. One way to reconcile this supposed paradox is

to delve into the emotional aspects of solitude – to explore why people feel differently when they alone than when they are with others. A cursory glance of the two sides of the debate points to solitude serving a positive, *restorative* function and an opposing view that solitude is antithetical to happiness and well-being. A more nuanced third explanation is that both are potentially correct, and thus, we should instead be asking: Under *what circumstances* and *for whom* is solitude experienced positively or negatively?

This question implies a dynamic view of emotions that is sensitive to situational circumstances and temporal effects. *Emotion dynamics* seeks to describe complex patterns in how emotions unfold over time and to explain the psychological factors that govern these changes (Kuppens & Verduyn, 2017). Emotions are dynamic because they fluctuate and self-regulate over brief intervals of time in complex, nonlinear patterns. Under this framework we might wonder how emotions change from one moment to the next when someone is *alone* versus when they are *with others*, and under what circumstances solitude is beneficial or detrimental to momentary affect.

However, because solitude is heterogenous, person-level and situation-level characteristics may impact how emotions change in the context of solitude. For example, person-level characteristics (e.g., introversion, preference for solitude) are important to consider as those who intrinsically enjoy solitude presumably report more positive emotions while alone. At an even finer-grained level of analysis, situation-level characteristics define an individual's cognitions and behaviours *during* solitude, which may be the difference in whether solitude is experienced as restorative or isolating.

Overview

This dissertation starts with a conceptual definition of emotions and the specific components that make up an emotional experience. The nature of emotions continues to be passionately debated among psychologists, neuroscientists, and philosophers. Thus, it is paramount to establish a firm conceptual understanding of emotions at the outset. Similarly, it is important to lay the conceptual groundwork for what *solitude* is. Not surprisingly, solitude has also been defined in myriad ways in psychological research and continues to be reconceptualized in light of advances in communication technology (see Coplan et al., 2018).

After these foundations have been established, the next section will weigh the extant evidence against and in support of the idea that solitude is good for one's emotions. This entails a more dynamic view of emotions that addresses the unfolding of emotions over time (i.e., emotion dynamics). Emotion dynamics integrates research on emotion regulation, coping, and well-being; and it is through this framework that we can best attempt to unravel the *paradox of solitude*. Here, the focus is more specifically on the role of solitude in emotion regulation (i.e., solitude as *restorative*). The Introduction concludes with the proposed *Contextual Model of Solitude and Emotion*, which posits that solitude is a heterogeneous phenomenon and that the effects of solitude on the dynamic unfolding of emotion over time vary as a function of person- and situation-level characteristics. In particular, the person-level characteristics include personality traits such as extraversion, preference for solitude, and social avoidance, while the situation-level characteristics include social context (i.e., alone versus with others), solitary activities (i.e., *what* one is doing while alone) and emotion regulation strategies.

This dissertation focuses on three studies of university students. Study 1 is an initial exploration of how solitude impacts change in emotion following an emotional event. Study 2

expands this by looking at different ways in which people spend their time alone and how these may differentially impact of our emotions. Finally, Study 3 uses an experience sampling paradigm to measure social context and emotion regulation in everyday life. This allows us to determine whether solitude predicts how we regulate our emotions and subsequent change in emotion.

Throughout this dissertation, a Bayesian paradigm for statistical inference is used. Bayesian statistics provides a more complete view of the *uncertainty* in our statistical models and is particularly useful when making inferences from multilevel models (McElreath, 2020; Stegmüller, 2013). Bayesian inference also combines powerfully with simulation and data visualization, which are featured prominently throughout the dissertation. These tools lay the groundwork for a framework that aims to predict emotion and emotion regulation from social context. Finally, the dissertation concludes with an integrative discussion that reviews the evidence for the proposed contextual model and explores its implications for people's well-being and mental health. This includes a discussion about solitude in the context of the COVID-19 pandemic, which at the time of this writing, has led to a proliferation of solitude around the world.

Defining Emotion

Psychologists are impassioned by the subject of emotions, and fundamental questions surrounding their nature and role in our well-being remain at the center of affective science. Despite heated debate about what emotions are, researchers have come to terms on a set of defining characteristics for emotional episodes (Scherer, 2005). These include: (1) *cognitive/evaluative processes*, including appraisal of the emotional stimulus; (2) *physiological arousal*, such as increased heartrate or pupil dilation; (3) *behavioural/expressive* responses, such

as facial activity; and (4) *subjective feelings*, which includes phenomenological qualia (i.e., what it *feels* like to have an emotion).

Although researchers disagree exactly how these four components fit together to ‘become’ an emotion, there is near consensus that emotions are caused by *appraisal* (e.g., Ellsworth & Scherer, 2003; Lazarus & Folkman, 1984; Ortony et al., 1990; however, see Bargh, 2011, for an opposing view). Appraisal is a simple perceptual-cognitive process assessing the significance of an internal or external event (Frijda et al., 1989; Lazarus & Folkman, 1984). Emotional events are appraised along several criteria that each speak to different aspects of the emotional stimulus and its implications. These five appraisal criteria are: (1) goal relevance, (2) goal in/congruence, (3) un/expectedness, (4) control, and (5) agency (Moors et al., 2013; Scherer, 2009). When an event occurs, it is appraised sequentially along these criteria, which has downstream implications for how the individual responds to that event and how it makes them feel. Contemporary appraisal theories champion the notion that emotion labelling (e.g., determining that one feels sad) is partly influenced by how the event is appraised along these criteria (e.g., goal relevance dictates the intensity of an emotion and goal in/congruence guides whether it makes us feel good or bad) (Ortony et al., 1990; Scherer, 2009).

Understanding the conditions that elicit emotions is a good place to start, but it does not fully explain what emotions are and how they are distinct from other “non-emotional” experiences. More pertinent to this discussion is the issue of how we should conceptualize the set of all affective experiences. Do labels like *fear* and *anger* refer to qualitatively distinct entities or are all emotions composed of quantitative differences along simpler psychological dimensions? Are we limited to instances of full-blown emotions or can we incorporate more diffuse experiences such as moods and feelings? Not surprisingly, theorists make different assumptions

about what should be included in a theory of emotion, but the largest theoretical divide is concerned with the question of whether there is a subset of *basic emotions*.

Basic emotions

The theory of basic emotions proposes that humans evolved to possess a universal, finite set of basic emotions characterized by distinct neurophysiological substrates, facial expressions, and behaviours, all of which can be traced back in our evolutionary ancestry (Ekman, 1992; Ekman et al., 1972; Izard, 1971; Tomkins & McCarter, 1964). Exactly how many and which emotions are deemed basic varies from one sub-theory to the next, but there is some agreement on six emotions: fear, anger, sadness, disgust, joy, and surprise (Ekman et al., 1972; Johnson-Laird & Oatley, 1992). Following in the footsteps of evolutionary biologists and anthropologists (e.g., Darwin, 1872), basic emotions are believed to be universal across situations, cultures, and even different species (Ekman & Cordaro, 2011). Evidence for this stems from early anthropological findings demonstrating that humans from different cultures can identify facial expressions signaling basic emotions (Duchenne, 1862/1990; Ekman et al., 1972).

Despite the appeal of the theory of basic emotions, it has gained criticism in recent years (e.g., Ortony & Turner, 1990; Russell, 2009). First, in contrast to the idea that basic emotions are universal, there is substantial variability between cultures and individuals in response to emotional situations (Barrett, 2009; Russell, 1994). Recognition and production of emotional facial expressions vary greatly across cultures in large part due to cultural-specific interpretations of emotional situations (Gendron et al., 2018). Another challenge for basic emotions is that the components underlying emotional responses are often *discordant*, meaning that an emotional response rarely involves coordinated changes across emotional components (Hollenstein & Lanteigne, 2014). For instance, basic emotions predict that anger is characterized by a

physiological/behavioural profile of a furrowed brow, blood rushing to the face and hands, pupils dilating, and a desire to yell or strike. However, this is more of a caricature than an accurate depiction of a typical angry response because situations that evoke anger prompt vastly different responses (Barrett, 2009).¹ Even a generous interpretation of the extant neurobiological evidence offers weak evidence of specific sets of affect programs and somatic responses underlying each emotion (Murphy et al., 2003; Quigley & Barrett, 2014).

Dimensional theories of emotion

Where basic emotions theory views emotions as a set of discrete categories, *dimensional* accounts of emotion see things along a continuum. Dimensional emotion theorists argue that one cannot draw a line separating ‘emotion’ from ‘non-emotion’ (Fogel et al., 1992; Russell, 2003). Moreover, as discussed previously, many emotional experiences do not fit neatly into categories like anger and fear, but, according to dimensional accounts of emotion, are more like a combination of simpler dimensions that make up the emotional landscape. In this way, all emotional experiences can be described along a few dimensions. Here, the term *affect* is more commonly used because it describes emotional experiences of varying intensity, even experiences that are completely neutral. In this dissertation, ‘affect’ and ‘emotion’ are used interchangeably unless it is necessary to distinguish among them.

To be more precise, the dimensions that underlie all of emotional experience collectively make up what is called *core affect*, referring to a free-floating and ever-present feeling during waking consciousness (Russell & Mehrabian, 1977; Russell, 1980; Russell, 2003). Core affect consists of two orthogonal dimensions: valence (i.e., pleasure vs. displeasure) and arousal (i.e.,

¹ Admittedly, basic emotions proponents do not conceive of basic emotions as fitting within neat boxes, rather, basic emotions reflect broader families of emotion responses with variable responses and outcomes (Ekman, 1992; Ekman & Cordaro, 2011). Notwithstanding, its critiques remain valid as there is little evidence to divorce emotion families from their roots in language (Gendron et al., 2018).

activation vs. deactivation) (Osgood, 1969; Russell, 1980; 2003), which make up the *Affect Circumplex* (see Figure 1; Russell, 1980; Yik et al., 2011). The advantage of this dimensional approach is that it acknowledges variation in emotional responses and experiences, which allows for a more dynamic exploration of emotions. Evidence of common neural underpinnings of core affect is stronger than that for basic emotions, and core affect has been found to be universal across human cultures and readily accessible in conscious recall (Edelman & Tononi, 2000, Emde et al., 1976; Wilson-Mendenhall et al., 2013).

There are also notable limitations to the valence/arousal account of affect (e.g., Larsen & Diener, 1992). Russell (2003) addresses many of these himself, pointing to ambiguity of ‘valence’ and ‘arousal’, complicating their use as anchors in self-report approaches to affect. Moreover, even amongst proponents of dimensional theories, there is disagreement as to whether valence and arousal adequately represent affective space, as some studies have offered evidence of three or even four dimensions (Fontaine et al., 2007; Warriner et al., 2013).

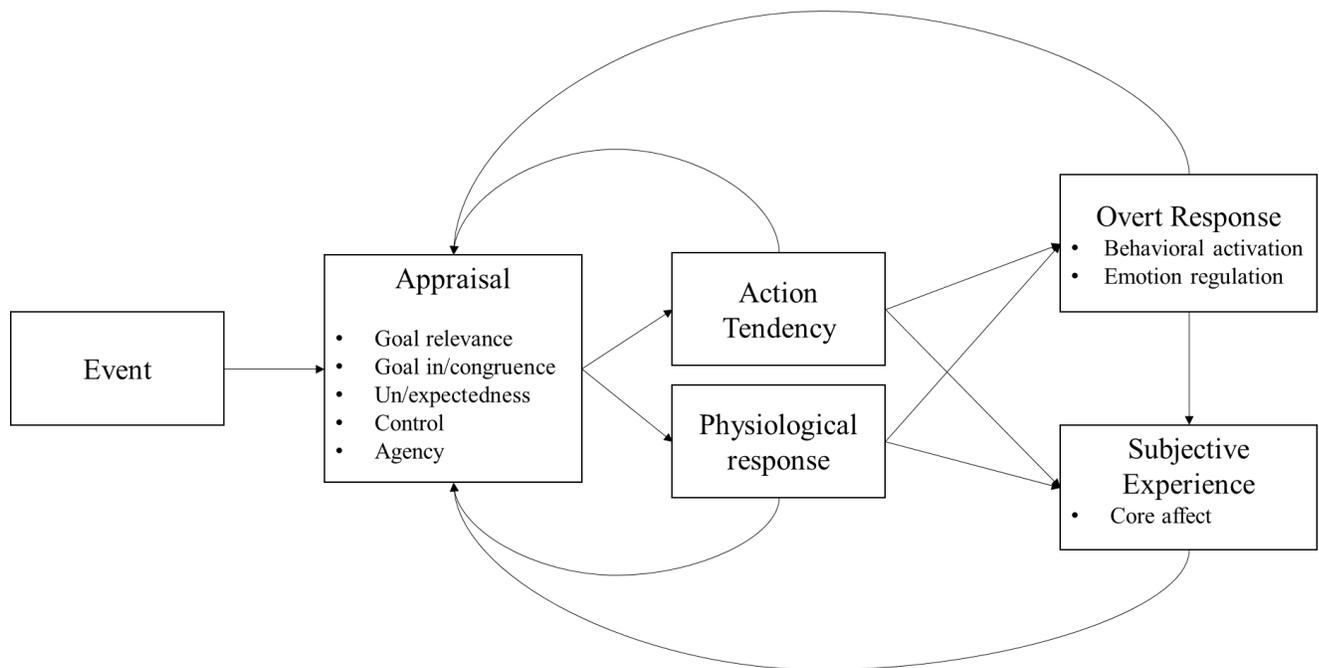
To their credit, Russell (2003) never wrote of valence and arousal as representing all of emotion experience. Instead, valence and arousal are useful concepts for organizing the complex and everchanging landscape of affect. We can imagine valence and arousal representing an uppermost level of a possible hierarchy of affective dimensions. Although we could investigate microscopic distinctions between varied emotional experiences and perhaps identify more granular dimensions of affect (see Cowen & Keltner, 2017 or Ortony et al., 1990 for granular views of emotion), it behooves researchers to begin their questions more broadly and to consider the fundamental properties of affect.

These issues notwithstanding, core affect is a reasonable description of how emotional experience can be represented, but the picture is still incomplete because it does not explain how appraisal gives rise to infinite possibilities of core affect states. Moors (2017) integrated research from appraisal theory and dimensional emotions theory to provide a deeper understanding of the causes of emotional states (see Figure 2). First, appraisal criteria (e.g., goal congruence, goal relevance, etc.) generate and modulate the content of emotional states. A stimulus is appraised along appraisal criteria, then an array of potential responses to the stimulus are mentally represented. The one with the highest utility is selected and is translated into an action tendency, which is a mental representation of action in response to a goal. The action tendency is translated

into an overt action (e.g., behavioural response) and a subjective feeling. This is an iterative process, such that if the response fails to address the salient features of the appraisal criteria, a second action option may be used (Carver, 2015; Scherer, 2009). Moreover, the experiential quality of core affect is compatible with appraisal criteria, such that arousal relates to goal relevance and un/expectedness, and valence corresponds with goal in/congruence (Moors, 2017).²

² The other criteria: control and agency, hypothetically map onto both valence and arousal. Control may also map onto a proposed third dimension of core affect, dominance (see Fontaine et al., 2007). However, dominance has received little attention in these theories, thus it will not be referenced as a component of core affect in this dissertation.

Figure 2. Dimensional Appraisal Theory of Emotion.



Notes: An event occurs and is appraised along the five appraisal criteria (e.g., goal relevance, *how relevant is this event to my goals?*). This simultaneously triggers an action tendency and a physiological response. The action tendency is translated into an overt response and the conscious realization of this makes up one's subjective experience. This is an iterative process, such that responses to an event are continuously reappraised.

So far, two competing theories of emotion have been discussed. Although the evidence weighs in favour of emotion dimensions, we should not be too quick to dismiss the value of basic emotions. Emotions may not be physiologically distinct, but it is undeniable that people use emotion labels like *happy* and *sad* to understand and share their emotional experiences (Gendron et al., 2018). These labels may capture more specific features about the causes and consequences of the emotional experience. In this way, basic and dimensional accounts of emotions speak to distinct aspects of the emotion experience, making them both valid ways of thinking about emotion.

In this dissertation, emotion is structurally viewed as core affect with appraisal as a theoretical mechanism. Core affect is a part of waking consciousness and, most relevant to this dissertation, undergoes fluctuations over time in response to internal and external events. This perspective offers the greatest potential to explore the role that solitude plays in emotions, consequently, moving us closer to elucidating the *paradox of solitude*. However, the final study of this dissertation uses a hybrid of basic and dimensional emotions, focusing on the *intensity* (continuous) of discrete states.

Conceptual Issues in the Definition of Solitude

Although scholars have theorized about solitude for decades (Goffman, 1971; Storr, 1988; Winnicott, 1958), much of the empirical work in this area is relatively recent. Within this burgeoning area of research are several different definitions and conceptualizations of solitude (Coplan, Ooi, et al., 2019). Accordingly, for the purposes of this dissertation, a number of assumptions and distinctions were made about solitude as a psychological construct.

First, it is important to be clear about what solitude is *not*. For example, although sometimes strictly defined in this regard (Wilson et al., 2014), herein solitude is not considered

synonymous with behavioural inactivity. Simply sitting alone in room doing nothing conflates solitude with boredom and ignores the vast number of activities that people often do while alone. In fact, many activities that people reportedly enjoy, such as reading or meditating, lend themselves to solitude. Thus, the conceptualization of solitude applied herein emphasizes an absence of social interaction without restricting other solitary activities. As well, solitude is not the same as *loneliness*. Loneliness is a perceived deficiency in the quantity and/or quality of one's social relationships (Hawkley & Cacioppo, 2010). Although feelings of loneliness are more likely to arise when one is alone (van Roekel et al., 2018), loneliness is an *evaluation* concerning the quality of one's social ties and may arise regardless of whether one is in the presence of others or not.

Thus, solitude can be defined as a state that reflects what the person is doing and/or where they are relative to others (e.g., Goffman, 1971). However, the distinction between being alone and being with others is still muddled at this point. On the one hand, solitude can be understood as *physical separation* from others, which entails limited opportunities for social interactions. In this way, we are considered alone when we are physically away from others. The ethnographer Erving Goffman (1971) used a theatre stage as a metaphor for self-presentation in everyday life – bringing credence to the remark that “all the world is a stage”. As we go about our day in the social world, we are front-stage and the world is our audience (see also Abbott-Chapman & Robertson, 2009). In contrast, solitude is considered as time “off stage”, when one is free from social demands. There is considerable evidence to suggest that people behave differently when they are around others. For example, adolescents are more likely to take risks and behave impulsively while in the presence of friends or strangers (Steinberg, 2007). More

pertinent to emotions, people experience more self-conscious emotions around others, particularly if they perceive to be a subject of attention (Lewis, 1993).

Goffman's (1971) view of solitude centered on *physical separation* from others. In contrast, Larson (1990) proposed that solitude is better characterized as *social separation*. In this way, one may be physically around other people, yet be considered alone if they are not engaged in any form of social interaction. This is a more inclusive definition of solitude, and it may fit better with how people use and understand terms like 'alone' or 'by myself'. This definition of solitude is best illustrated by the person sitting alone in a crowded cafeteria, surrounded by others, yet not interacting with them.

However, defining solitude is further complicated by the ubiquity of online communication. Prior to the widespread accessibility of the internet, Larson (1990) contemplated solitude in the context of different forms of telecommunication, which was then largely limited to television and conversing over the phone. Using Goffman's (1971) definition, the issue of technology is irrelevant because solitude is defined merely as whether you are physically in the presence of others. However, Larson (1990) conceptualized solitude as an absence of social exchange, and he argued that interacting with others via technology indeed represented social exchange. To this effect, Larson made an important distinction between interactive and passive technologies (see also Rozgonjuk et al., 2019 for more recent usage of this terminology). Larson argued that interactive technology, such as talking over the phone, could not be considered solitary, whereas passive technology, such as watching television, could be solitary.

Nearly thirty years after Larson (1990) proposed his definition of solitude and now our society is awash in interactive technology of a different kind. Social media platforms are designed with the purpose of connecting people, and research indeed suggests that people use

social media to address their social gratification needs (Kushin & Yamamoto, 2010; Wang et al., 2012). Of course, there are diverse types of social media and people may use social media to serve different purposes (e.g., information vs. social connection). Some ways of engaging with social media are more interactive than others, which has implications for our understanding of solitude. For instance, instant messaging may be considered highly interactive because it typically entails a conversational back and forth of messages. Conversely, scrolling through online social media feeds, passively absorbing others' media posts may be considered passive because the exchange is unidirectional (Leung, 2015). Of course, the lines become blurred when considering instances in which people are posting comments in response to others or if someone is posting to a wide audience of followers (e.g., Twitter or Instagram), most of whom are strangers. We can even speculate about how to define solitude in the context of interacting with artificial intelligence, which is becoming increasingly human-like (Khanna et al., 2015). The point of this is not, of course, to get us lost in a conceptual morass, but to highlight the challenges in objectively defining solitude.

A final definition of solitude concerns its cognitive and experiential features. Moving beyond one's physical state (i.e., around others or not; interacting or not), solitude involves cognitions and experiences concerning how people view themselves relative to others (Averill & Sundararajan, 2014; Long et al., 2003). In other words, *feeling* alone may be different from physically *being* alone. For example, feeling alone at a crowded party or feeling a transcendental connection with a spiritual entity during a solitary pilgrimage both exemplify the subjective nature of solitude. Importantly, this helps to explain why people have such diverse solitude experiences (i.e., solitude as good or bad). At its worst, solitude precipitates feelings of loneliness when people are unable to meet their needs for social interaction (Goossens, 2018;

Hawkley & Cacioppo, 2010). At its best, solitude may take on an almost divine quality, enabling personal enlightenment in the form of self-discovery or self-enrichment (Averill & Sundararajan, 2014; Suedfeld, 1974).

Clearly, there is no encompassing definition of solitude. Drawing upon these different perspectives, solitude can be said to include features of separation (physical and social; e.g., Goffman, 1971; Larson, 1990) and subjective states associated with *feeling* alone (Averill & Sundararajan, 2014). Navigating this conceptual morass is important because different aspects of solitude may be more relevant to one's emotions. As will be discussed in subsequent sections, it is possible, for example, that physical separation from others may be an essential ingredient for solitude being restorative because it relieves people of social pressures (e.g., Goffman, 1971; Nguyen et al., 2018). Fortunately, these perspectives can easily be incorporated together by asking participants to provide details on their reported states. For example, by asking participants to describe their current state as (1) interacting with someone, (2) others nearby but not interacting, or (3) alone (e.g., Lay et al., 2018). In this dissertation, two definitions of solitude will be assessed and compared, the first being *physical separation* (e.g., physically alone with no other people present), and the second *social separation* (e.g., others nearby but not interacting).

Solitude and Emotions

These detailed conceptualizations of solitude and emotions provide an opportunity to begin to unravel the so-called *paradox of solitude* (Galanaki, 2015; Larson, 1990). The paradox is concerned with a mismatch between the proposed benefits of solitude (e.g., restorative, creative, productive) and individual's reported negative emotions during solitude. On the one hand, self-reports indicate that people recognize the benefits of solitude in terms of privacy, relaxation, self-reflection, creativity, and emotion regulation (Long et al., 2003). Moreover,

people often predict that having time to themselves will be more enjoyable than meeting someone new (Epley & Schroeder, 2014; Zelenski et al., 2013). On the other hand, a cursory review of the experimental literature suggests that solitude makes us feel worse compared to being around others (e.g., Reis et al., 2017; Wilson et al., 2014). In general, spending time alone seems to be a more unpleasant state compared to time spent in the company of friends, family, or even strangers (Kahneman et al., 2004; Reis et al., 2017; see also Coplan et al., 2018, for a review). Simply being alone is associated with elevated levels of cortisol, a hormone implicated in stress (Matias et al., 2011; Pauly et al., 2017). In a similar vein, Wilson et al. (2014) found that many participants experienced boredom during a 15-minute period of social isolation, such that a large proportion of them opted to self-administer electric shocks rather than doing nothing. Thus, it appears that even brief instances of social separation evoke unpleasant emotions.

Moving away from the more momentary implications of solitude and looking at its longer-term implications also provides insight into how time alone affects emotions. Not surprisingly, it seems that the more time people spend alone, the more likely they are to experience its emotional drawbacks (Vanhalst et al., 2017). For example, extended periods of solitude increase the risk of experiencing loneliness (van Roekel et al., 2018). Loneliness serves an evolutionarily adaptive purpose – signifying that one has insufficient social resources and subsequently prompting action to engage in social interaction (Cacioppo & Hawkley, 2009). Although the underlying mechanism of loneliness is postulated to be adaptive, chronic loneliness causes people to turn inward and perceive social situations as more threatening, thus sustaining their withdrawal (Cacioppo et al., 2017; Goossens, 2018). Because of its links with stress and depression, loneliness poses a risk for cardiovascular disease, substance abuse, and even mortality (Hawkley & Cacioppo, 2010; Seeman, 1996; Valtorta et al., 2018). Thus, extreme

social isolation, such as in the case of chronic loneliness, is widely recognized as both a predictor and consequence and psychopathology (Ernst & Cacioppo, 1999).

Just as being alone seems to be experienced negatively, being around others generate positive feelings (Lucas et al., 2008; Vittengl & Holt, 2000). People in the presence of others are report higher positive affect (Shackman et al., 2018). Reis et al. (2017) found that roughly 70% of “fun” experiences included another person. In experimental studies, participants who are asked to interact with strangers both in and outside the lab reported a more positive experience during that activity (Epley & Schroeder, 2014; Sandstrom & Dunn, 2014; Zelenski et al., 2013). Moreover, in a recent meta-analysis of 20 studies comparing momentary affect in social and solitary contexts, Liu et al. (2019) found a small-moderate effect size in the link between social interaction and positive affect. However, social interaction quality (e.g., level of closeness with social partner) was found to be a stronger predictor of affect beyond the mere presence of another person. As another example, Shackman et al. (2018) found that during instances when people were with close others (e.g., friends or romantic partners) they reported markedly higher positive affect, whereas this increase was attenuated when they were with distant others (e.g., classmates, acquaintances).

What is it that makes social interaction experienced more positively than solitude? One explanation is that *shared experiences* amplify emotions (Boothby et al., 2014). In the company of others (especially close others), chocolate tastes sweeter and artwork is more aesthetically pleasing (Boothby et al., 2014; 2016). Moreover, shared experiences do not necessarily require social interaction, meaning that simple activities such as watching a movie with a friend can boost its enjoyability (Boothby et al., 2016). This last finding is noteworthy in light of our understanding of solitude, because it hints at a difference between physical separation and social

separation in how events are experienced. Despite Larson's (1990) argument that social separation is a sufficient definition for solitude, it appears that being around others without interacting shares some emotional similarity to regular social interaction. This is additional impetus for considering both aspects of solitude in terms of their relations with emotions.

Boothby and colleagues (2014; 2016) also found that shared experiences are amplified for negative events, with bitter chocolate tasting more unpleasant (Boothby et al., 2014) and stressful experiences being more stressful when the experience is shared with others (Nahleen et al., 2019). Although their methodology was limited to amplifying the taste and likability of chocolate, their findings are consistent with developmental research on the amplification of negative emotions during co-rumination (rehashing negative events with others; Rose et al., 2007; Waller & Rose, 2013; however, see Van Zalk & Tillfors, 2017 for an opposing view). The finding that this amplification occurs for positive and negative emotions is evidence that the connection between social interaction (or at least the physical presence of others) and positive emotions is not as clear as some studies may suggest.

Consequently, solitude, as well, may have a more complex relation with emotions. As stated earlier, affective experience is made up of two orthogonal dimensions, valence and arousal (Russell, 2003). This view of emotions is particularly relevant in the context of solitude because solitude is purportedly conducive to decreasing arousal (Nguyen et al., 2018, see more on this below). Although high arousal in and of itself is not necessarily unpleasant (positive high arousal states include jubilation), highly arousing *negative* states are often equated with stress (Yik et al., 2011). This is consistent with the idea that solitude has restorative properties, at least in terms of reducing negative arousal, such as stress or tension. Overall, this implies a more time-dependent relation between solitude and emotions, whereby solitude impacts how emotions change from

one moment to the next. Thus, taking solitude into the context of emotion dynamics will help us to understand how solitude affects the trajectory of emotions.

Emotion Dynamics

Emotion dynamics refers to patterns of change and regularity in the experiential, physiological, and behavioural elements of emotion, and their antecedents and consequences (Kuppens & Verduyn, 2017). Emotions are not static events, rather, they are part of a dynamic system that is intrinsically self-regulating, has multiple inputs/outputs, and fluctuates over time in complex patterns (Hollenstein, 2015). A feature of such a system is that it can take on myriad possible states, some that occur frequently and others that rarely, if ever, arise. Core affect represents this infinite affective state space, thus, at any time, an individual's emotional state can be depicted as a point in this hypothetical two-dimensional space.

Over multiple assessments, a system's *trajectory* within the state space can be depicted, and it is here that patterns of change and regularity emerge. States that recur frequently are called *attractors* because they pull the trajectory of the system toward that state (Gleick, 1987; Hollenstein, 2015). A helpful analogy of an attractor is to think about Einstein's relativity and how planetary bodies bend space-time, pulling objects into their orbit. For instance, one's affective home base (i.e., baseline mood) is an attractor state because at any given moment the individual is pulled toward that state (Kuppens, Oravecz, et al., 2010). The stronger the attractor the more energy is required to move outside of it, the same way that a ball requires external energy to roll upward on a slope. Simply put, people can experience a wide variety of emotional states, but some states occur more frequently and last longer.

Attractors and state-spaces help to conceptualize the dynamic nature of affect, but how does emotion dynamics play out in people's lives? Kuppens and Verduyn (2017) organized the

study of emotion dynamics into four basic principles: inertia, regulation, contingency, and interaction. *Inertia* posits moment-to-moment stability in affect and describes patterns of minimal variability (Cunningham et al., 2013; Koval et al., 2012). *Regulation* states that emotions are in a continuous state of regulation (Gross, 2015; Kappas, 2011; Kuppens & Verduyn, 2015). *Contingency* is a reiteration of appraisal theory, which states that changes in emotion are caused by appraisal of events external to themselves (Lazarus & Folkman, 1984). Finally, *interaction* implies that different components of emotions (physiological, experiential, behavioural) vary over time in sometimes concordant or discordant fashion (Hollenstein & Lanteigne, 2014). Inertia and regulation are elaborated upon in the subsequent section, as they are relevant to understanding how solitude is implicated in the unfolding of emotion over time.

Inertia.

When circumstances are stable so too are emotional states. One's current emotional state carries forward into subsequent states (i.e., emotional auto-correlation), and moment-to-moment changes are gradual (Kuppens, Allen, et al., 2010). At most times, this stability is centered around relatively neutral states, such as an individual's affective *home base* (Kuppens, Oravecz, et al., 2010). Nevertheless, inertia does occur outside of the affective home base. Persistent negative emotional inertia (i.e., being stuck in a state of negative emotion) appears to be a risk factor for psychological maladjustment. This type of emotional rigidity is associated with emotion regulation difficulties (e.g., regulation rigidity) and may prognosticate the onset of major depression (Koval et al., 2012; van de Leemput et al., 2014). For instance, adolescents who exhibited greater positive and negative emotion inertia during a filmed interaction with a parent were more likely to receive a diagnosis of major depression two years later (Kuppens et al., 2012). Furthermore, van de Leemput et al. (2014) reported that a critical slowing down (i.e.,

temporary period of elevated inertia) predicted the onset of a major depressive episode among healthy participants.

One of the proposed mechanisms underlying inertia is mood congruence, whereby people remember old information and appraise new information in a way that is coherent with their current emotional state, thus resulting in fewer and less intense alterations in core affect (Forgas, 1995). For instance, participants who were experimentally led to feel more pleasant predicted that future events would also be more pleasant (Sanna, 1999). For most people, the culprit of extended emotional inertia is invariable circumstances and repetition (Sansone et al., 1992). This is why changing behaviours that have become routine can make them enjoyable once more (O'Brien & Smith, 2019).

Bringing this into the context of solitude, one can surmise that extended periods of either solitude or social interaction breeds inertia. This possibility was raised earlier in the context of solitude and loneliness, whereby being alone for too long can create a self-sustaining state of loneliness in which social information is appraised more negatively (Cacioppo et al., 2017; Goossens, 2018). Is it also true that extended social interaction can be a source of emotional inertia? Some have proposed that being around others for too long is fatiguing because social activities demand more cognitive resources (Cain, 2012; Fleeson et al., 2002; Kaplan, 1995; Repetti, 1989). Often, a case is made for introverts experiencing fatigue from socially demanding tasks, such as behaving outside their comfort zone (Cain, 2012). However, experimental findings are largely at odds with this explanation. For example, Zelenski et al. (2013) revealed that when introverts were asked to temporarily behave extraverted they reported more enjoyment than when they behaved normally. This is consistent with a large body of literature suggesting that

extraverted behaviour is linked to positive moods and is more likely to energize rather than deplete (Fleeson & Gallagher, 2009; Zelenski et al., 2012).

Still, because these studies only tested participants in brief, laboratory sessions, they do not address the consequences of *extended* social interaction. Few studies have investigated length of time with others as a factor in experiencing fatigue. Leikas and Ilmarinen (2017) used an experience sampling approach to explore extraverted behaviour in daily life and its association with daily affect. They found that during instances when participants engaged in highly extraverted behaviour, they experienced immediate positive affect. However, roughly three hours following intense extraverted behaviour, participants reported greater fatigue. Those who reported meeting more people in a given day reported even more fatigue at the end of the day. Interestingly, this delayed fatigue occurred regardless of trait extraversion, suggesting that long periods of time with others is exhausting for both extraverts and introverts. Unfortunately, the researchers did not investigate whether subsequently resorting to solitude allayed fatigue.

In a somewhat different vein, some researchers have suggested that extended social interaction poses threats to well-being because it impedes our basic need for solitude (Buchholz & Catton, 1999; Winnicott, 1958). The idea is that all people have an innate need for time alone, which, when thwarted, diminishes one's well-being. Depending on personality and situational characteristics, this need may be stronger for some, but the core of this argument is that everyone needs at least a modicum of time alone (Larson, 1990). However, only recently has this assertion received empirical support. Coplan, Hipson et al., (2019) introduced the term *aloneliness* to refer to a state in which one is dissatisfied with their opportunities to be alone. Following extensive validation of this new construct, they found that solitude-oriented participants (i.e., high motivation and preference for solitude) who spent less time alone during the preceding week

reported high loneliness (i.e., craving for solitude) compared to those who were less solitude-oriented or spent plenty of time alone. Interestingly, socially-oriented individuals who spent less time alone also reported more loneliness than socially-oriented individuals who spent more time alone, supporting the view that loneliness occurs regardless of dispositional traits (albeit with varying strength).

Taken together, these findings provide some evidence that a lack of opportunity for solitude may elicit negative emotions, particularly among those who gravitate toward solitude. However, it remains to be seen whether loneliness is best described in terms of emotional inertia and whether solitude may be relevant in alleviating this inertia. Indeed, this is the focus of the next section on emotion regulation in the context of solitude.

Regulation.

If emotional inertia is about how emotions stabilize over time, regulation is about how emotions change over time. The principle of *regulation* implies that emotions are in a continuous state of regulation (Gross, 2015; Kuppens & Verduyn, 2015). At its most basic level, regulation is simply the natural tendency of emotions to change via positive and negative feedback loops (Carver, 2015; Hollenstein & Lanteigne, 2014; Kappas, 2011). Emotions intensify when the system is in a state of continuous positive feedback and return to baseline in a state of continuous negative feedback. For example, exposure to a stressful stimulus is a form of positive feedback that intensifies one's emotional state, whereas engaging in strategies to regulate this stress constitutes a form of negative feedback, provided that the strategy is effective (Gross, 2015). This type of regulation usually occurs implicitly, without realization (Mauss et al., 2007). However, emotion regulation can be more explicit and goal-oriented, as when one attempts to feel more pleasant or changes emotions to increase productivity (Tamir et al., 2008).

Regulation is an intrinsic property of emotions, thus there is no such thing as unregulated emotion (Thompson, 2011). Kappas (2011) refers to this property as auto-regulation, which is not to be confused with *automatic regulation* (i.e., emotion regulation processes that occur outside of conscious awareness, Mauss et al., 2007). From this view, the basic constituents of an emotional experience (e.g., physiology, expressivity, etc.) are themselves regulatory processes, since they function (in part) to eventually bring affect back to baseline (Kappas, 2011). Thus, all things being equal, a person who experiences acute stress would be expected to feel less stressed after a few moments. Others have likened this process to a thermostat; specifically, a damped oscillator model, which views momentary change in affect as tending toward baseline but with minor oscillating fluctuations (Chow et al., 2005).

These processes are perhaps less obvious when we think of regulating mood more generally, but the underlying emotion dynamics are the same (van de Leemput et al., 2014). Indeed, the processes governing regulating are *stronger* at more extreme emotional states but are in continuous operation regardless of whether one is enraged or mildly peeved (Kuppens, Oravecz, et al., 2010). Overall, it is clear that emotions themselves represent basic allostatic processes that tend toward stability. Still, we would be remiss to stick with such a mechanistic view of emotion regulation. Indeed, emotion regulation is multi-faceted and encompasses a variety of cognitive and behavioural processes whose function is to change emotions.

The principle of regulation described thus far has been limited to processes of *auto-regulation*. However, people are capable of changing how they feel either by engaging in different behaviours or simply changing how they think about their feelings (Gross, 2015; Tamir, 2009). The study of emotion regulation encompasses all aspects of emotional change, including implicit and explicit forms of regulation (Thompson, 1994; Westen, 1994). Explicit regulation is

deliberate and often requires more cognitive resources. For instance, people who experience anxiety on a plane may alleviate their anxiety by closing their eyes, taking deep breaths, and counting backwards. These strategies may become more implicit³ and automatic over repeated uses (Mauss et al., 2007), such as when someone reflexively averts their gaze during a scary movie. It is also convenient to categorize emotion regulation as behavioural (e.g., slamming the door after an argument) or cognitive (e.g., reflecting on how a bad situation could have ended differently) (Garnefski et al., 2001). Of course, these delineations are somewhat arbitrary as people often engage in multiple forms of regulation at any given time.

Distinguishing emotion regulation and coping.

Before delving deeply into the types of strategies that people use to regulate emotions, it is important to address some definitional issues. One of the primary sources of confusion in the study of emotion regulation concerns the difference between *emotion regulation* and *coping*. Westen (1994) and others (see Gross, 2013) make a conceptual distinction between emotion regulation and coping on the premise that they differ in focus and in their temporal characteristics. It is argued that coping is predominantly focused on decreasing negative affect and takes place over a longer period of time (Carver & Connor-Smith, 2010; Gross, 1998). In contrast, emotion regulation is more focused on immediate emotional states and it places equal emphasis on upregulating positive emotions as it does on downregulating negative emotions.

Although this delineation is helpful from a conceptual standpoint, it represents a false dichotomy (Compas et al., 2017). For example, there is substantial overlap in the content of measures that assess emotion regulation versus coping (e.g., ‘reappraisal’ in emotion regulation, ‘positive reinterpretation’ for coping; Carver, 2015; Garnefski et al., 2001). Further, from the

³ In practice, the term ‘explicit regulation’ is rarely used and this concept is usually just called ‘emotion regulation’ unless it is being directly contrasted with ‘implicit regulation’.

perspective of emotion dynamics, the psychological processes underlying coping and regulation are one and the same (e.g., Blanke et al., 2020; van de Leemput et al., 2014). However, researchers may conceptually distinguish between the two based on timescale and focus. For example, when considering how well a person is adjusting to a tumultuous life event, it is useful to describe their patterns of regulation in terms of coping, but it should be clearly understood that coping is just a distilled aggregation of a series of regulatory processes. There is little reason to believe that emotion regulation and coping involve distinct processes or arise in separate circumstances. Accordingly, for the purpose of this dissertation, the term emotion regulation will be used to broadly denote change in emotion and the sources that drive this change. This is more in line with emotion dynamics research, which takes a finer-grained perspective on change in emotions over time.

Emotion regulation strategies.

There are a number of ways to regulate emotions. An *emotion regulation strategy* refers to an implicit or explicit process that decreases, increases, or maintains affect toward a desired state (Gross, 2013; Thompson 1994). The *Process Model* of emotion regulation (Gross, 1998; 2015) is the most widely used framework for understanding how emotion regulation strategies are involved in modulating affect over time. It posits that emotion regulation strategies have an effect at specific points along the sequence of an emotional event.

At the earliest stage of the Process Model are situation-focused strategies (situation selection and situation modification) that involve taking actions to alter the likelihood or impact of an emotional response. Next, are attention-deployment strategies, which involve directing one's attention to alter the emotional impact of a situation. *Distraction* is one such strategy that involves shifting one's attention away from a distressing stimulus or engaging in some alternate

activity (Thiruchselvam et al., 2012). Then, cognitive change strategies alter the way one thinks about the situation, in turn, modulating its emotional significance. *Reappraisal* is a specific type of cognitive change that involves reflecting and reinterpreting the significance and consequences of a situation (Ray et al., 2010). Lastly, response modulation strategies act on changing the expressive, physiological, or behavioural components of the emotional response. This may take the form of relaxation or, in a more pathological case, *suppression*, which entails inhibiting emotion expression (Gross & Levenson, 1997).

Emotion Regulation Strategy Selection

Emotion regulation strategies are the key players in emotion regulation, so we must first understand which contexts tend to elicit which strategies. Two factors that are critical in determining which emotion regulation strategies people use are: (1) emotion regulation goals, and (2) the characteristics of particular strategies. Emotion regulation goals motivate us to regulate our emotions in the first place, but they also act as standards by which to evaluate how effective our regulation efforts are (Kruglanski et al., 2002; Tamir, 2016). We typically use strategies in order to improve our current emotional state, such as moving from a negative state toward a more positive one. These are called *hedonic* goals and constitute the majority of emotion regulation goals (Tamir, 2009). However, not all emotion regulation goals involve simply increasing positive affect and decreasing negative affect. Sometimes, we engage in *instrumental* goals that serve to increase the likelihood of a desired outcome (Kalokerinos et al., 2017; Riediger et al., 2009; Tamir, 2016).

Which strategy we use depends a great deal on these goals. For instance, participants who watched a sad video and were instructed to then increase their positive affect (i.e., hedonic goal) were more likely to use distraction, whereas participants instructed to decrease their

negative affect more often used rumination (Millgram et al., 2019). In other set of laboratory experiments, participants who were motivated to act confrontationally instead of collaboratively were more likely to use strategies to upregulate their anger (e.g., watch an anger-inducing film) (Tamir & Ford, 2012). Importantly, these studies show that the relation between situational context and strategy selection is mediated by emotion regulation goals. In other words, strategy selection is not directly guided by the situation itself but by a person's goal that arises in the context of that situation.

Once a goal is activated there is still the matter of selecting a particular strategy in service of that goal. Here, distinguishing features of the emotion regulation strategies play a key role in which strategy is selected. Two features that researchers have focused on include *engagement*: how much information specific to the emotional event one takes in, and *effort*: the amount of cognitive resources (e.g., information processing) required to successfully use the strategy (Parkinson & Totterdell, 1999; Sheppes et al., 2014). Strategies such as reappraisal and suppression are high engagement and high effort because they involve evaluating and reorganizing information about the emotional situation or reducing emotion expression and experience. Rumination is high in engagement but lower in effort as repetitive thoughts about the event occur without much cognitive effort and can even be intrusive. Engagement (confusingly, engagement is also a strategy itself as well as a characteristic of strategies) is similarly high engagement/low effort as it involves taking in all information about the emotional event, but not cognitively manipulating it in any way. Finally, distraction and relaxation tend to be low engagement, low effort strategies because they involve distancing oneself from the situation and/or engaging in alternate behaviours (Sheppes et al., 2009; Sheppes & Meiran, 2008). Selecting a particular strategy comes down to a trade-off between

these characteristics and how well the strategy addresses one's emotion regulation goal. In the context of negative events, if maximizing pleasure and minimizing emotional pain is the goal, then a person should be most likely to select a low engagement/low effort strategy like distraction because it is easy and relatively effective (Sheppes et al., 2009).

Emotion Regulation Strategy Effectiveness

Strategies vary in their efficacy and have different consequences on psychopathology and well-being. The bulk of this research compares the effectiveness of cognitive change vs. response modulation strategies; namely, reappraisal versus suppression (Aldao et al., 2010; Webb et al., 2012). Experimental findings overwhelmingly suggest that reappraisal is more effective in downregulating negative emotions and upregulating positive emotions compared to suppression (Ehring et al., 2010; Gross, 1998; Szasz et al., 2011; Webb et al., 2012). Reappraisal is theorized to be more adaptive than suppression because reappraisal acts earlier in the regulatory process, decreasing the emotional impact (John & Gross, 2004). Conversely, suppression may be somewhat effective in the short-term but is often maladaptive in the long-term because it does little to remove or change the event causing the emotion (Aldao et al., 2010).

Other commonly assessed emotion regulation strategies include distraction, reflection, and rumination, all of which have their effect predominately at the attention deployment stage. *Distraction* is thought to be an adaptive form of attention deployment because it diverts attentional and cognitive resources away from the emotional stimulus (Aldao et al., 2010; Sheppes et al., 2009). *Reflection* is a neutral, non-evaluative process of attending to emotional events and thoughts in a calm, meditative manner (Trapnell & Campbell, 1999). *Rumination*, in contrast, is a maladaptive form of self-reflection that involves repetitive and unproductive

focusing on one's feelings and their causes and consequences (Nolen-Hoeksema et al., 2008). Rumination is implicated in depression because pervasive and maladaptive thought patterns perpetuate depressed mood (Papageorgiou & Wells, 2001). More generally, rumination prolongs and intensifies negative feelings, regardless of whether one is depressed (Millgram et al., 2019; Résibois et al., 2018). This occurs in several ways. As outlined in Nolen-Hoeksema et al. (2008), rumination makes information about a negative event more readily available for recall and it interferes with problem solving strategies. Additionally, chronic rumination impedes willingness to seek social support and makes others less inclined to offer social support in the long-term (Nolen-Hoeksema & Davis, 1999).

Overall, results from experimental studies suggest that strategies such as reappraisal, reflection, and distraction are more effective compared to suppression and rumination (e.g., Webb et al., 2012). However, a major limitation of experimental studies is that they fail to take into account the spontaneity and diversity of emotion regulation in daily life. In real life, people do not use all emotion regulation strategies equitably and some situations may call for certain strategies over others (Bonanno & Burton, 2013). Accordingly, researchers are increasingly turning to *ecological momentary assessment* (EMA) to assess spontaneous use of emotions and strategies (Csikszentmihalyi & Larson, 1987). A crucial advantage of EMA is that it considers the context in which emotion regulation takes place.

Using this approach, researchers have found that people use some strategies disproportionately. For example, Heiy and Cheavens (2014) found that in the context of negative emotions, people reported using distraction and rumination most often, whereas reappraisal and suppression were used relatively infrequently. This is despite their finding that reappraisal strategies were still among the most effective in reducing negative emotions, which is consistent

with experimental results (e.g., Ehring et al., 2010). In another study with university students, distraction was the strategy used most often, whereas reappraisal and social support seeking (another less commonly studied strategy) were the least common (Brans et al., 2013). Brans et al. (2013) further found that suppression and rumination were associated with decreases in positive affect and increases in negative affect, whereas reflection served to increase positive affect.

Researchers have also found that the usage and effectiveness of some strategies depends on the context in which they are used. For example, people tend to use reappraisal in low emotion intensity situations and distraction in high emotion intensity situations (Sheppes et al., 2011). More recently, Troy et al. (2018) reported that suppression was the most commonly reported strategy in the context of daily stressors, suggesting that it is used as an initial response to negative emotions (and may be adaptive in some cases; e.g., Keltner & Bonanno, 1997).

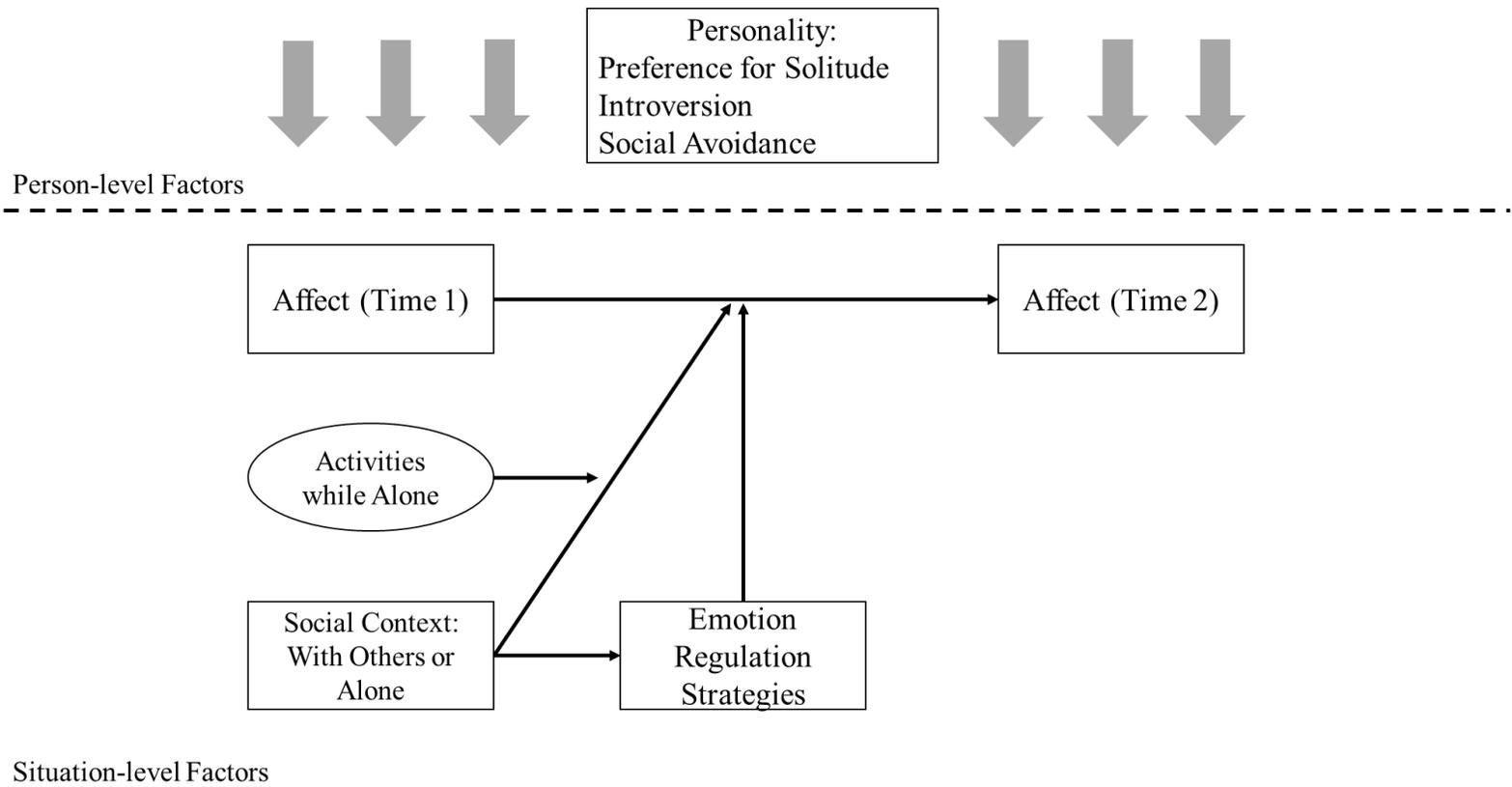
Taken together, evidence from EMA studies suggests that people use different strategies across different contexts, and that some strategies may be more effective than others in these different contexts. We can apply this to the context of solitude and emotions by exploring how solitude impacts, not only emotions, but the choice and effectiveness of certain emotion regulation strategies. For instance, being alone may increase the likelihood of choosing some strategies over others. As well, solitude may be associated with different patterns in emotion change compared to when one is around others. From this perspective, the conceptual frameworks of emotion dynamics and emotion regulation will be applied to explore how *solitude* impacts emotions over time.

Emotion and Emotion Regulation in the Context of Solitude

Thus far, we have established that solitude is often experienced as unpleasant and, overall, is less conducive to one's well-being, despite claims that it can be beneficial. We have

also established that emotions are dynamic and change over time via processes such as emotion regulation. It is the goal of this dissertation to clarify questions surrounding how solitude changes our emotions, not only in terms of whether solitude is “good” or “bad”, but in terms of the *processes* that relate solitude (or more generally, *social context*) to how we manage our emotions and our subsequent emotional experiences. These ideas are captured in the proposed theoretical framework, which is referred to throughout this dissertation as the *Contextual Model of Solitude and Emotion* (see Figure 3).

Figure 3. Contextual Model of Solitude and Emotion



In this model, we differentiate between two types of variables: *person-level* and *situation-level*. Most of the action in this model is situation-level because we are interested in change in affect at a particular point in time and how it varies as a function of circumstances inherent in the situation. Person-level variables act as latent underpinnings to the action that goes on at the situation level (as denoted by the grey arrows). Because we are interested in emotion dynamics, central to the model is the process relating *Time 1 Affect* to *Time 2 Affect*: representing change in affect over time. Below this, we introduce contextual factors that we expect to modulate this change in affect. Each study in this dissertation focuses on one or more components of this model, in the hopes that, together, they inform us about the larger model in its entirety. In this section, we introduce the main components of this model as well as the state of the extant literature with respect to each component.

Solitude and Change in Emotion

How does social context (i.e., solitude vs. social interaction) relate to our everchanging emotional state? It has previously been discussed that solitude is less conducive to one's current happiness than being in the company of others (Shackman et al., 2018). For example, people on a commuter train who were asked by researchers to talk to a stranger reported more happiness and fulfillment compared to commuters who were asked to go about their regular routine or think pleasant thoughts (Epley & Schroeder, 2014). But the relation between solitude and momentary happiness is likely only part of the story. Perhaps solitude is particularly helpful for *regulating* emotions when they get out of hand. The question we might then ask is: When feeling stressed or upset, does being alone help or hinder to reduce these negative feelings? Does solitude help us move from feeling calamitous to calm? Here, we review three lines of research that speak to

these questions: (1) coping with extreme adversity, (2) avoiding others to cope with anxiety, (3) solitude as restorative.

Seeking comfort in the face of adversity.

There is little doubt that in the face with extreme adversity, people tend to seek the comfort of others. For example, during the London Blitz of 2nd World War, people sought out others for protection and emotional support (Janis, 1951). People who receive social support during natural disasters are better able to weather psychological distress (Arnberg et al., 2012). Marginalized individuals who experience prejudice, violence, and other injustices seek out members of their community (Singh et al., 2011).

These findings are consistent with evolutionary theory. In particular, *Social Baseline Theory* posits that the human brain is wired to expect access to mutually beneficial and personally rewarding social relationships (Coan & Maresh, 2014; Coan & Sbarra, 2015; Coan et al., 2006; Tomasello et al., 2005). When this expectation is not met (i.e., in the absence of social interaction), the brain perceives a deficit in available resources resulting in maladaptive energy expenditure. *Social Baseline Theory* suggests that social resources are valued to the same extent as bioenergetic resources (e.g., glucose). Therefore, deprivation of social interaction impairs functioning much in the same way as depletion of bioenergetic resources. Indeed, these conjectures are reciprocated in evolutionary research on loneliness, which posits that loneliness signals that one's social relationships are insufficient, resulting in a conservation of bioenergetic resources (Cacioppo et al., 2017; Goossens, 2018; Hawkley & Cacioppo, 2010).

Much of the evidence in support of *Social Baseline Theory* comes from neuroimaging studies. The brain appears to be more “at rest” when social resources are abundant, whereas aberrant neurological activity is apparent in the absence of social interaction (Coan & Sbarra,

2015; Zhang et al., 2013).⁴ Social proximity also has an impact on how people weather threats in the environment. In an fMRI study, participants who anticipated receiving electric shocks had attenuated threat-related neural activity when they held their spouse's hand (Coan et al., 2006). Even holding a stranger's hand appreciably reduced threat-related neural activity compared to going it alone. Other studies have found similar effects across widely different contexts. For instance, people underestimate the steepness of hills when accompanied by a friend (Schnall et al., 2008). However, as with the handholding study, the effect was stronger if the participant shared a close relationship with their companion. Thus, the emotion regulatory benefits of social interaction are likely more attributable to the positive effects of friendship and less so to the physical presence of others.

Additional evidence comes from research on socio-economically disadvantaged adolescents, which found that social context (e.g., alone vs. peers vs. family) is associated with change in emotions following minor stressors (Uink et al., 2017). The results suggested that being with peers reduced the intensity of negative emotions (sadness, jealousy, and worry) and increased positive emotions (happiness). During adolescence, peers are a source of social support that may be particularly effective in reducing stress (Larson & Richards, 1994). It is important to consider, however, that adolescents may be compelled to suppress their emotions when they are around their peers to avoid expressing their feelings. Moreover, the study was with disadvantaged youth who are prone to experiencing more stressors and likely have less social support in general (Hurd et al., 2018).

⁴ Coan and Sbarra (2015) interpret Zhang et al.'s (2013) findings as evidence that the brain is more "at rest" when others are around. An alternative interpretation would be to say that the brain appears more "threat vigilant" when alone. It is worth noting that these studies took place in unfamiliar environments with an expectation of an unfamiliar threat (electric shock).

Looking at a different sample, Stone et al. (2019) found that for anxious youth, social support strategies (i.e., being with another person during a stressful event) did not decrease negative affect. Only *co-distraction* (i.e., engaging in distracting activities with others) appeared to alleviate negative emotions for these youth, especially among boys. These results are mirrored in analyses exploring the drawbacks of engaging in *co-rumination*, which tends to exacerbate negative emotions, especially in girls (Rose, 2002; Rose et al., 2007). Taken together, there is considerable evidence suggesting that in times of stress and adversity, people benefit from the comfort and support of others.

Solitude as avoidance coping.

Avoidance coping is the term used to describe a coping style or family of emotion regulation strategies that involves distancing oneself (physically or mentally) from a stressor (Carver & Connor-Smith, 2010; Parkinson & Totterdell, 1999; Thayer et al., 1994). If one experiences stress and anxiety when they are around other people, then solitude may itself be a form of avoidance coping. In terms of the Process Model (Gross, 2015), this type of solitude seeking can be considered a form of situation selection and situation modification, which are anticipatory strategies where one selects or changes their environment to pre-empt negative emotions. The connection is obvious for shy or socially anxious individuals, for whom social situations evoke fear and concern over social evaluation, in turn, prompting avoidance strategies (Brown et al., 2007; Eisenberg et al., 1998).

However, viewing the emotion dynamics of solitude through the lens of avoidance coping introduces some conceptual issues. Avoidance coping is intimately linked to personality characteristics such as shyness as well as mental health disorders such as Social Anxiety Disorder and schizophrenia (Sette et al., 2020). Seeking solitude to cope with intrusive socially

anxious thoughts is not the same as seeking solitude for enjoyment or relaxation. Additionally, avoidance coping is usually only effective in alleviating immediate negative emotions, but it has harmful implications to one's well-being if it becomes habitual (Kashdan et al., 2006).

Therefore, social avoidance as a personality trait may be helpful in distinguishing whether one ultimately benefits from seeking solitude, but it does not necessarily serve as an argument that solitude on its own is detrimental.

Solitude as restorative.

Most scholarly work on the benefits of solitude has focused on its purported restorative effects (i.e., promoting restfulness, relaxation, and rejuvenation). Early research on the restorative properties of solitude was pioneered by Suedfeld (1974) who was particularly interested in the rehabilitative function of social isolation. At the time, researchers were intrigued by the psychological effects of sensory deprivation and constructed elaborate sensory deprivation tanks (effectively, a covered bathtub). A participant or patient would lay in the tank, in complete darkness and devoid of sound (Suedfeld, 1980). Extravagant historical accounts report of participants experiencing hallucinations, out-of-body experiences, temporary cognitive impairment, and even complete recovery from mental illness (Haythorn, 1973). Although skeptical of these outlandish claims, Suedfeld and Kristeller (1982) applied this technique (which they labelled *Restricted Environmental Stimulation Technique*, or REST) as a means of stress reduction. The findings are largely anecdotal and limited to clinical cases, but generally support Suedfeld's claim that sensory deprivation decreases stress (e.g., Forgays & Belinson, 1986).⁵

⁵ Research in the area of sensory deprivation seems to have halted since the days of Suedfeld's work. Therapeutic benefits were elusive, tanks were found to be cumbersome and impractical, and ethical issues arose. Nevertheless, this work spawned a cottage industry of sensory deprivation clinics that claim to cure disease.

Of course, solitude is not analogous to sensory deprivation. But we can draw some parallels between certain solitary experiences (e.g., meditation, deep relaxation) and Suedfeld's work on REST. For example, mindfulness meditation is often practiced in quiet, solitary settings, to prevent distractions and calm the mind (Kabat-Zinn, 2003). Mindfulness has gained widespread popularity and spawned an entire industry as a technique for reducing stress and promoting well-being (e.g., Davis & Hayes, 2011; however, see Toneatto & Nguyen, 2007, for a critical review). Taken together, specific techniques for relaxation and mindfulness, which often occur in the context of solitude, may be helpful for alleviating stress. However, these techniques do not emphasize the importance of being alone, and it is conceivable that the benefits of sensory deprivation or mindfulness may still arise in the presence of others. Thus, solitude is arguably not a necessary condition to reap the rewards of mindfulness; rather, it may only serve to amplify these benefits.

Others have argued that the restorative benefits of solitude are best understood as counteracting the exhaustion and stress that arise from daily life (e.g., Kaplan, 1995; Repetti, 1989). *Attention Restoration Theory* postulates that prolonged demands on attentional resources are fatiguing, thus prompting people to seek environments that are restorative (Kaplan & Kaplan, 1989; Kaplan, 1995). People who perceive that their attentional resources are strained may find solace in activities that place minimal cognitive demands but still provide rich sensory stimulation (Herzog et al., 1997). Such environments often include natural surroundings away from other people because these offer myriad sources of stimulation (e.g., rich colors, pleasant smells, minimal noise) while posing minimal demands on cognitive resources. These environments afford opportunities to “clear one's mind” – so to speak – which acts via the same

principles underlying the emotion regulation strategy *distraction* (Korpela et al., 2018; Sheppes et al., 2011).

The quintessential environment for promoting attention restoration is a natural environment, thus most research has examined the restorative effects of being alone in nature (Kaplan, 1995; Korpela et al., 2018). Being alone in nature is often reported to promote personal reflection and promote well-being (Herzog et al., 1997). As an example, people who were experimentally made to feel fatigued (engaging in a difficult cognitive task) were instructed to either walk alone in nature or through a city (Berman et al., 2008). Those that walked in nature performed better on a subsequent attention task. Corroborating evidence comes from research by Korpela and colleagues (Korpela et al., 2001; Korpela et al., 2002), who have investigated how having a favourite place is beneficial to one's well-being. Most adults and even children report that they have a favourite place where they can be alone that offers restorative benefits (Korpela et al., 2002), and people overwhelmingly report natural environments as being among their favourite places (Korpela et al., 2001). Notwithstanding these findings, it is difficult to isolate the benefits of being in nature from the proposed benefits of solitude, as these studies fail to distinguish between the two. As in the case for mindfulness and sensory deprivation, it is unlikely that solitude is a necessary condition for attention restoration.

Accordingly, recent research has explored solitude as emotion regulation *irrespective* of one's environment and behaviour. Nguyen et al. (2018) conducted a series of experimental manipulations and daily diaries to examine whether spending 15 minutes alone would result in a change in affect compared to spending fifteen minutes with another person. Importantly, this study used a repeated-measures design to explicitly assess participants' emotional states before and after solitude. Moreover, the researchers used a two-dimensional approach to emotions that

is conceptually similar to the circumplex model of emotions (Russell, 1980). Specifically, they used a modified version of the *Positive and Negative Affect Schedule* (PANAS; Watson & Tellegen, 1985) that included low arousal positive and negative emotions (e.g., calm and sleepy, respectively). Thus, valence and arousal were not assessed as dimensional but as scores on different emotion labels theorized to belong to each quadrant of the affect circumplex.

Overall, Nguyen et al. (2018) found that participants who were alone reported decreased high arousal emotions and increased low arousal emotions compared to those who were with others. This occurred for both positive and negative valence emotions, supporting the view that solitude predominately influences the arousal dimension. The relation between solitude and change in arousal makes sense for a couple of reasons. One is that arousal corresponds to physiological activation and is higher in contexts when one is engaged in a task, such as interacting with another person. Another reason involves how arousal pertains to the appraisal process. Arousal is theorized to be contingent on appraisal criteria corresponding to goal relevance and un/expectedness (Moors et al., 2017; Scherer, 2009), and being alone for a brief period is unlikely to impact one's goals nor involve unexpected outcomes.

Interestingly, in Nguyen et al.'s (2018) subsequent conditions, the deactivation effect was consistent regardless of whether the participant was occupied (e.g., reading; Study 2) or instructed to think positive thoughts (Study 3). However, having choice over one's thoughts versus being told what to think during solitude did have an impact on deactivation; such that deactivation of high arousal positive emotions was mitigated for participants who had the choice to think of whatever they wanted. Finally, the authors replicated these findings in a more ecologically valid context using daily diary reports of time spent alone during the week (Study 4). Those who reported higher autonomous motivation for solitude (i.e., preference for solitude)

reaped more benefits in terms of decreased loneliness and increased calmness. The importance of autonomy is further demonstrated in research by Chua and Koestner (2008) who found that autonomous solitude was not associated with negative outcomes such as loneliness and decreased well-being. Thus, periods of solitude may deactivate intense emotions, and the degree to which solitude is beneficial depends largely on whether solitude is self-directed (autonomous) or imposed.

Additional research using experience sampling methods corroborates these findings. Lay et al. (2018) assessed a mixed sample of community and university students' daily solitary experiences and classified these experiences as positive (i.e., calming) or negative (i.e., lonely). Positive solitary experiences, which were notably characterized by decreased high arousal negative affect (e.g., Nguyen et al., 2018), constituted 43% of all solitary experiences, offering compelling evidence for the heterogeneity of solitude (Lay et al., 2018). Moreover, state desire for solitude (as measured during each momentary assessment) was positively associated with everyday positive solitary experiences. In other words, those who desired solitude at that moment were more likely to experience their solitude as calming. In contrast, *trait* rumination and self-reflection were positively associated with negative solitary experiences (i.e., high negative arousal). Although rumination has been identified as a maladaptive means of regulating emotions (Nolen-Hoeksema et al., 2008), the link between trait self-reflection and negative solitude is somewhat surprising. The type of introspective and meditative self-reflection that is often touted as a benefit of solitude, may be more difficult to actuate in daily life, instead more commonly taking on characteristics of self-critical rumination or boredom (Cacioppo et al., 2014; Lay et al., 2018; Wilson et al., 2014).

In summary, these findings lend credence to the role of solitude in reducing arousal. However, here we need to be careful about using the word ‘restorative’ when in fact we should use the word ‘deactivating’. A restorative solitary experience implies that the person experiences an increase in valence (e.g., higher happiness) as well as a decrease in arousal. This would correspond to cases when a person feels calmer and more relaxed during solitude, and the extant research is far less conclusive regarding this association. Hence, the term deactivation will be used to refer to reduction in arousal without an increase in valence.

Moderators of the Association between Solitude and Change in Affect

Given the vast heterogeneity among people *and* among solitary experiences, it would seem unlikely that all instances of solitude would lead to deactivation. We have seen some evidence of solitude having differential impact on affect as a function of autonomy (Lay et al., 2018; Nguyen et al., 2018), and it is likely that depending on *what* one is doing while alone, solitude may be more or less deactivating, perhaps even restorative. We now look toward potential moderators of the association between solitude and change in affect. Two we focus on here include solitary activities (situational-level) and personality/motivation (person-level).

Solitary activities.

Whether one is watching TV, reading a book, listening to music, or in calm reflection, most people are doing something when they are alone.⁶ How do different solitary activities impact the emotion dynamics of solitude compared to when we are around others? One approach is to compare affect during instances in which people are *actively* doing something while alone versus when they are simply thinking (Buttrick et al., 2018; Wilson et al., 2014). The phrase

⁶ Even someone reportedly doing ‘nothing’ while alone would nonetheless be engaged in passive mind-wandering. We only exclude instances in which one is sleeping while alone because during sleep one is not cognitively aware and thus has no core affect.

‘actively doing something’ refers to overt behaviours (e.g., exercising, browsing social media, eating, etc.), which contrasts with cognitive activities (e.g., daydreaming, thinking pleasant thoughts).⁷

How do these different types of activities impact affect during solitude? In one out of a series of experiments, Wilson et al. (2014, Study 8) found that participants who were instructed to spend 12 minutes alone with their thoughts experienced less positive affect compared to participants who were told to engage in an activity of their choice. This finding was subsequently replicated across eleven countries (Buttrick et al., 2018). The authors suggested that intentional thinking is less pleasant because it requires cognitive effort (Westgate et al., 2017). It is important to realize, however, that participants in the ‘doing’ condition were free to choose their own activities, which is key because having autonomy during solitude has been found to make it more enjoyable (Chua & Koestner, 2008; Nguyen et al., 2018).

Moreover, the activities that people choose are more often those that require minimal cognitive exertion while still providing stimulation (e.g., watching TV, browsing the internet, etc.; Buttrick et al., 2018). More recent findings offer additional evidence that ‘doing’ is more enjoyable than ‘thinking’. In a sample of high school students, Hipson, Coplan, et al. (2021) found that those who tended to spend their time alone thinking, planning, ruminating, or doing nothing, reported lower positive affect. In another study, Coplan, Hipson et al. (2021) reported that engaging in *intrinsically motivated solitary activities* (e.g., hobbies, art) are more likely to satisfy the need for solitude (i.e., make solitude more fulfilling and enjoyable).

⁷ This simplistic distinction is for the purpose of convenience. There is no denying that people may be engaged in overt behaviours while they are thinking about things, or that one’s attention may shift from a task to their inward thoughts.

Behavioural activities also likely impact how solitude is experienced. Outside of what is already known about the benefits of ‘doing’ over ‘thinking’ (Buttrick et al., 2018; Nguyen et al., 2018, Study 2; Wilson et al., 2014, Study 8), surprisingly little is known about how different activities impact the experience of solitude. Although loneliness is conceptually distinct from solitude, it is notable that lonely individuals do not tend to engage in different activities from those who are not lonely (Queen et al., 2014; Russell et al., 2012). Looking more specifically at what people do when they are alone, evidence suggests that certain activities and environments may be conducive to solitude’s restorative effects (e.g., alone in nature). However, no study has directly compared different activities, such as listening to music, watching TV, or reading a book. In a recent study, many students also reported engaging in leisure or hobbies (e.g., listening to music, reading, drawing etc.) while alone (Hipson, Coplan, et al., 2021), which are often considered to be more rewarding than productive or routine behaviours (Iso-Ahola, 1980; Kleiber et al., 1986).

Recent time use studies over varying age groups indicate that solitude is often a context for increased screen time (Leung, 2015). Early research suggests that watching TV while alone is associated with less enjoyment of solitude and more loneliness (Kubey, 1986; Perlman et al., 1978). Later studies among older adults found links between loneliness and internet use (Sum et al., 2008), and links between tablet usage and reduced momentary stress (Leung, 2015). Interactive and immersive forms of screen time are taking center-stage, especially among children and adolescents, which has drawn concern from parents and physicians (Twenge et al., 2019; though see Orben & Przybylski, 2019 for a more critical view). Although these technologies may offer more mental stimulation and greater opportunities for social interaction, *excessive* use of interactive technologies (including social media) is problematic for a small

percentage of children and adolescents (Rehbein et al., 2015; Twenge et al., 2019). All of this is to say that solitude may be more or less restorative depending on what one is doing *and* thinking while they are alone.

Extraversion and preference for solitude.

Among the plethora of terms in the extant literature used to describe someone who is drawn toward solitude, the most commonly used is *introvert*. Extraversion (of which *introversion* refers to its opposing pole) is a dimension of personality that captures individual differences in sociability; and thus tends to be negatively associated with time spent alone (Carver et al., 2000; Zelenski et al., 2014). However, extraversion also captures sub-traits that have *less* to do with solitude, including assertiveness, activity level, reward sensitivity, and impulsivity (Carver et al., 2000). Nevertheless, there is substantial overlap between extraversion and general motivations toward solitude; therefore, these findings will be discussed here.

Results from numerous studies and meta-analyses point to a robust link between extraversion and positive affect (Costa et al., 1981; Steel et al., 2008; Wilt et al., 2012). This has led some to suggest that positive emotionality is simply a core feature of extraversion (Tellegen, 1985), whereas others have postulated that extraverts are happier because they are better at maintaining positive moods and repairing negative moods (Lischetzke & Eid, 2006). This has direct implications within an emotion dynamics framework because it suggests that extraverts can avoid negative emotional inertia while maintaining positive feelings.

Accordingly, it may be tempting to conclude that introverts are doomed to be less happy than their extraverted counterparts (for a review of such arguments – see Zelenski et al., 2014). However, because much of this research is correlational, it is difficult to identify which aspects of extraversion account for heightened positivity. Extraverts tend to seek out activities that are

more stimulating and conducive to positive emotions, regardless of the social context of these activities. In other words, extraverts gravitate toward activities that have big emotional pay-offs, such as spontaneous traveling or attending parties. As for introverts, some scholars have suggested that they may be more content at lower intensities of positive affect on a regular basis because they find prolonged periods of intense positive stimulation fatiguing (Geen, 1997; Hills & Argyle, 2001; Rusting & Larsen, 1995; Smillie et al., 2012). This postulation highlights an intriguing crossover with research on *ideal affect* in different cultures; where it has generally been found that people from collectivistic cultures strive for calmer emotional states relative to those in individualistic cultures who desire highly activated states (Tsai, 2017).

As well, much of the speculation underlying solitude's proposed restorative effects comes from the literature on introversion. It is argued that introverts are prone to exhaustion in social contexts and seek solitude as a means to "recharge their batteries" (Coplan et al., 2018). Scholars continue to debate these interpretations, but it is important to reiterate that introversion is conflated with characteristics that are less relevant to spending time alone (e.g., assertiveness). For this reason, we may want to turn to more specific concepts that specifically capture desire for solitude.

Moving away from extraversion, we can further narrow in on attitudes toward solitude (e.g., Burger, 1995; Cramer & Lake, 1998; Goossens, 2014; Thomas & Azmitia, 2019). Some individuals are intrinsically motivated to spend time alone and, as a result, tend to enjoy solitary experiences and may reap additional benefits from being alone (Leary et al., 2003; Nguyen et al., 2019). It is important to highlight that these individuals spend time alone because they value solitude in and of itself, not because being alone helps to alleviate anxiety.

There are a number of terms used to describe attitudes and preferences toward solitude. For example, Goossens and colleagues (Goossens, 2014; Goossens & Marcoen, 1999) used the term *affinity for aloneness* to describe enjoyment of solitude and positive reasons for seeking solitude. In their studies, affinity for aloneness was not associated with feelings of loneliness, when controlling for motivations to avoid others. Others have used the term *unsociability* to refer to a non-fearful preference for solitude (Asendorpf, 1990; Coplan et al., 2004; Nelson, 2013). Unsociability is often used in a developmental context to refer to children who are content to play alone, as opposed to those who are socially wary (e.g., Coplan et al., 2004; Coplan & Weeks, 2010). More recently, however, unsociability has been applied across diverse developmental contexts, including emerging adulthood (Nelson, 2013). Regardless, research in children (Coplan et al., 2004), adolescents (Bowker & Raja, 2011), and emerging adults (Nelson, 2013) all indicate that unsociability is a more benign reason for spending time alone (compared to shyness or social avoidance) and may even be beneficial in some instances (Daly & Willoughby, 2020; see also Coplan, Ooi et al., 2019 for a review).

Overall, however, there is reason to be critical of some of these assertions because such studies perpetually find links between positive and negative motivations toward solitude (Goossens, 2014). In many cases, it is only when *controlling for* social avoidance that positive links between affinity for aloneness and well-being are found. This circles back to the *paradox of solitude* in that people may claim that they enjoy solitude, while simultaneously experiencing it as unpleasant.

More recently, there has been a focus on *self-determined solitude* (Chua & Koestner, 2008; Thomas & Azmitia, 2019), which captures intrinsic motivations for solitude. Thomas and Azmitia (2019) found that self-determined solitude was positively associated with well-being

and not associated with loneliness, social anxiety, or depression among emerging adults. Moreover, Nguyen et al., (2019) found that an autonomous (i.e., intrinsic) motivation for solitude was associated with fewer depressive symptoms, less loneliness, and even a greater sense of relatedness to others. Lay et al. (2018) found further evidence that trait desire for solitude predicted a greater likelihood of experiencing solitude positively (i.e., low arousal positive affect). Notwithstanding the different terminologies, this dissertation broadly refers to the tendency to want to spend time alone as *preference for solitude*.

Solitude and Strategy Selection

The *Contextual Model of Solitude and Emotion* also focuses on how emotion regulation strategies are chosen in the first place. Previous research suggests that when we are in the company of others we tend to prioritize instrumental regulation goals, particularly socially motivated goals that foster interpersonal relationships and improve social standing (English et al., 2017). Sometimes this entails expending more regulatory effort or employing strategies that forgo hedonic concerns. As such, people are more likely to use suppression (or agree that suppression is the ideal strategy) when they are in the company of others (Daros et al., 2019; English et al., 2017; Tang & Huang, 2019) because this strategy serves an instrumental goal characterized by hiding their emotions from others. Other researchers have similarly found that suppression is more likely to occur when in the company of non-close others (i.e., acquaintances) compared to close others (Benson et al., 2019).

Beyond suppression, there has been some research on how social context influences the selection of other strategies. For instance, distraction (diverting one's attention from the emotional event) and reappraisal (re-evaluating information about the event) appear to be less influenced by our social surroundings (English et al., 2017), suggesting perhaps that these

strategies can be easily implemented in either social context. However, there is less research on strategies like rumination and relaxation. Although there is some evidence that ruminating while alone increases negative feelings (Merolla et al., 2019), this does not imply that rumination is used less often in the context of solitude. Indeed, being alone may be a context for rumination to proliferate, especially if one finds themselves alone with nothing to do but think (Wilson et al., 2014; 2019). However, this research contrasts with studies on *co-rumination* (i.e., ruminating with others) suggesting that it is associated with negative affect and less effective coping (Rose et al., 2007).

An Integrative Perspective on the Contextual Model of Solitude and Emotions

The goal of this dissertation is to better understand how solitude impacts emotion dynamics in which contexts and for which people. Unraveling the *paradox of solitude* means taking a contextual approach to studying solitude – examining the links between solitude, emotion, and emotion regulation, and how these links vary as a function of personality and situational characteristics like solitary activities. This dissertation includes three separate studies exploring the links between solitude and emotion. Each study focuses on somewhat different components of the overarching theoretical framework, but together they provide insight into these complex workings. Study 1 involves the use of a novel retrospective report to examine how people's change in affect varies as a function of social context and emotion regulation strategies. Study 2 examines how different solitary activities interact with time alone to predict positive and negative affect. Finally, Study 3 uses an experience sampling paradigm to investigate how solitude predicts emotion regulation strategy selection and effectiveness. These data are then analyzed using Bayesian statistics. Bayesian statistics is somewhat unconventional in the psychological sciences, but it offers many advantages in terms of fully understanding the

model’s uncertainty. This next section provides a brief conceptual-level overview of Bayesian statistics, its advantages, and how it compares with a more traditional Frequentist approach.

What is Bayesian Statistics?

Bayesian statistics gives us a way of quantifying *uncertainty* based on all available information (Gelman et al., 2013; McElreath, 2020). It essentially asks the question: *given what we already know, how does our data modify our uncertainty about the phenomena of interest?* In more concrete terms, we want to know the *likelihood* of our parameters of interest (e.g., mean, slope, difference score, etc.), given the data and our prior knowledge. Moreover, we do not just want to know which parameters are most likely (i.e., maximum likelihood), we want to obtain the full probability distribution of parameter values and their likelihood.

Bayesian inference centers on what is called the *posterior distribution*. The posterior distribution tells us the likelihood of the parameters given the data, and is defined by Bayes’ theorem as:

(1)

$$p(\theta|y) = \frac{p(y|\theta)p(\theta)}{p(y)}$$

θ represents what we do not know – the parameters in our model – and y represents what we do know – the observed data. The quantity on the left is the posterior distribution – the likelihood of the parameters given the data. On the right and in the numerator, we have two quantities: $p(y|\theta)$ denotes the probability of the data given the parameters. This quantity is called the *likelihood*. The likelihood tells us, for fixed data, how likely the data are to have been generated from a given set of parameters.

The other quantity in the numerator, $p(\theta)$, is the *prior* distribution. We use priors to express our uncertainty about the parameters before our model “sees” the data. This could mean

incorporating expert knowledge about what we think the parameters are, but more commonly (at least in a research context), priors express how we think the parameters are distributed/generated. For example, in regression we have one or more linear coefficients, β_j . If we are working in standardized units (which we often do in Bayesian statistics), we know that extreme values of β_j are unlikely, whereas values closer to 0 are more likely.⁸ Thus, we incorporate this prior knowledge by allowing β_j to come from a normal distribution with a mean of 0 and perhaps a standard deviation of 5. In fact, our choice of standard deviation for the prior allows us to express how confident we are in our prior. In this way, priors offer a mathematical way to incorporate skepticism in the model.⁹ In most practical situations, we use a standard deviation that restricts extreme values but gives enough room for the data to tell most of the story.

Finally, in the denominator of Equation 1 is the quantity $p(y)$. This quantity, called the *marginal likelihood*, captures the probability of the data. It is also sometimes called the “evidence” (MacKay, 2003). It is this quantity that makes Bayesian statistics so computationally challenging because we often cannot express each possible way the data could have arisen. One way we arrive at an estimate of this quantity (and therefore an estimate of the posterior distribution), is to use what is called Markov Chain Monte Carlo (MCMC; Gilks et al., 1995).

This dissertation does not delve deeply into the theory and mathematics behind MCMC, but instead offers a conceptual overview of how MCMC relates to modern Bayesian inference.

⁸ We are assuming we have no information to tell us otherwise, or perhaps we want to be conservative and avoid biasing the results in any one direction prior to the data.

⁹ There are different types of priors for different purposes. Vague priors assign credibility to large range of parameter values and are used when one wants the prior to have minimal impact on one’s conclusions. Regularizing priors assign credibility to a narrower range of values and are often used when one wants to avoid overfitting or express some degree of skepticism toward extreme values. On the farthest end of the spectrum, skeptical priors assign credibility to a very narrow range of values. The most common approach is to use weakly regularizing priors, which helps to eliminate the possibility of extreme values, but still allows the data to tell the story. In practice, the more data one has, the less influence the prior has on the results.

First, a Markov chain describes a sequence of states where each subsequent state depends on only the previous state in a probabilistic way. The second part, Monte Carlo, refers to the method of repeated sampling from a distribution to evaluate a population distribution. Bringing these two together, we arrive at a method that samples from a distribution (of parameter values) and the location of each sample is probabilistically dependent on the previous state. The current state-of-the-art MCMC algorithm is Hamiltonian Monte Carlo (HMC; Duane et al., 1987; Hoffman & Gelman, 2014) and it has a few additional sophistications that are beyond the scope of this dissertation. Suffice to say that HMC performs diagnostic checks on the MCMC so that we can be more confident that the posterior distribution has been adequately sampled (in a later section we review some of these diagnostics). We use the software Stan (Carpenter et al., 2017) to specify and run MCMC.¹⁰

Why Use Bayesian Statistics?

It is important to note that Bayesian statistics is a different paradigm from what is referred to as Frequentist statistics. In other words, it is not as if we are using different types of models, but the fundamental way in which we approach statistical inference is different. Here are a few reasons to adopt a Bayesian paradigm.

Reason 1: Distributions over point estimates

First, Bayesian statistics provides us with the complete posterior distribution instead of point estimates, so we get a more complete picture of the uncertainty in our inference. The posterior distribution is then interpretable directly in the language of probability. For example, a 95% *credible* interval in Bayesian statistics tells us where 95% of the population parameter values lie, whereas a 95% confidence interval in Frequentist statistics tells us that with large

¹⁰ ‘Stan’ is not an acronym, but is meant to pay homage to Stanislaw Ulam (1909-1984), inventor of MCMC.

number of samples, 95% of such calculated confidence intervals would include the true value of the parameter, which is a more cumbersome interpretation. This is more of a “philosophical” advantage of Bayesian statistics, as it rarely translates into practical benefits (at least in context of social science research where the focus lies predominately in parameter estimation instead of prediction).

Reason 2: Regularization and model flexibility

Perhaps more compelling is the second reason: Bayesian models are more flexible and require fewer ad-hoc adjustments. Consider a type of model used in Study 3 of this dissertation: the *varying effects multinomial regression* model which involves a categorical outcome modelled on a series of covariates, with varying intercepts/slopes for nested observations (see Koster & McElreath, 2017 for more details). In a classical Frequentist design, we would need to tack on an ad-hoc penalty term to avoid overfitting, and the constraints imposed by the categorical outcome could result in singular solutions. Moreover, the model would perform poorly with a small sample size with potentially biased estimates. In contrast, Bayesian statistics implicitly incorporates regularization (i.e., avoiding overfitting) through the use of priors, thus precluding the need for penalty terms. Additionally, small samples are not an issue as they simply translate into more posterior uncertainty. This is perhaps the biggest practical advantage of Bayesian statistics over Frequentist statistics, and although it is often true that these two approaches give similar results in practice, when we encounter a regularization problem (e.g., varying effects models), they can give different conclusions (McElreath, 2020).

Reason 3: Bayesian workflow – infer, compare, simulate

A final advantage is the emphasis away from statistical significance and toward model comparison and simulation. Model comparison is not uniquely Bayesian and there are many

Frequentist applications that focus more holistically on models, such as Structural Equation Modelling. But in Bayesian statistics, model comparison is an integral part of the analytic workflow even when dealing with the simplest types of models. There is good reason for this. We want our models to do well in the real world, not just on sample data. Simulation is also inherent to Bayesian statistics and is an extremely useful tool for understanding how the model “makes sense” of the world. For example, we will often use a tool called *posterior predictive simulation* to better understand, given a statistical model, what would happen on unseen data.

Addressing the Criticisms of Bayesian Statistics

Are there reasons *not* to use Bayesian statistics? A common concern with Bayesian statistics is that it is more subjective due to its inclusion of prior information. However, many have argued that this does not make Bayesian statistics any more subjective than Frequentism (Bishop, 2006; MacKay, 2003). For instance, in Frequentist statistics, the choice of a particular estimator, penalty term, or cut-off for statistical significance (e.g., $p < 0.05$). are all inherently subjective in a sense. Of course, there is nothing special about $p = 0.05$, it is just a convention. All of this is to say that it is impossible to do inference without making assumptions. In fact, incorporating prior information can be viewed as an asset because of it aids in regularization or, in situations when we have credible prior information, it makes our predictions better.¹¹

Perhaps a more valid, practical criticism of Bayesian statistics is that it is computationally challenging and less efficient than Frequentist estimation. MCMC requires time and computer cores. Models of the kind described in this dissertation can take several hours and all that time

¹¹ Another criticism of priors is that they provide the analyst with a way to bias the results in favor of a desired outcome. Although this is technically true, it would be blatantly obvious if it had happened. Why this is often presented as a criticism is a mystery. A dishonest analyst could perform any number of “modifications” to their data to achieve a desired result. Choosing an extremely biased prior would be neither an efficient nor a sneaky way to do this.

does not guarantee the model converges in the end. Despite these drawbacks, Bayesian statistics offers many advantages and is an undeniably powerful tool for inference.

Bayesian Workflow

Although each study in this dissertation is somewhat unique in terms of procedures for data preparation, cleaning, and descriptive analysis, it adheres to a systematic four-step analytic strategy for modelling and inference:

Step 1: Model diagnostics

The primary model diagnostics for Bayesian models are trace plots, \hat{R} (not to be confused with R^2), and divergent transitions. Trace plots permit an informal check for model convergence, indicated by the appearance of “hairy caterpillars”. \hat{R} also evaluates model convergence. \hat{R} ranges from 1 to ∞ , where values closer to 1 are better. In fact, we will typically view any \hat{R} greater than 1.05 (an arbitrary but conventional value) as constituting a problem (Gelman, Lee, & Guo, 2015).

Another diagnostic is divergent transitions. The presence of multiple divergent transitions suggests that the Markov chain has not adequately explored certain regions of the parameter space and thus calls into question the validity of the obtained coefficients (Leimkuhler & Reich, 2004). The typical solution for divergent transitions is to re-parameterize the model so that it is mathematically more efficient (e.g., scaling and centering the predictors or switching from a centered to a non-centered parameterization). These diagnostics are not presented for each model, but the models all have \hat{R} values between 1 and 1.01 and are without divergent transitions.¹²

¹² Trace plots are not shown because they are not particularly interesting. Trace plots for all models were visually inspected.

Step 2: Interpretation of model coefficients

Interpretation of model coefficients is a standard step regardless of whether one is doing Bayesian analysis. Recall that Bayesian statistics gives us a whole distribution of coefficients for each covariate. The standard is to give the mean posterior distribution and a 95% credible interval around this mean. This interval tells us that there is a 95% probability that the true parameter lies within the range, given the data and prior evidence. This interpretation sounds like a confidence interval in the Frequentist setting, and many would incorrectly say that it is the same. However, a Frequentist confidence interval tells us that with large number of samples, 95% of such calculated confidence intervals would include the true value of the parameter.

Step 3: Visualizing and simulating the posterior

Generally, there are two powerful ways to visualize and evaluate the posterior distribution (see Gabry et al., 2019 for a more detailed overview). One way is to generate expected values given some set of predictor variables – called visualizing the posterior distribution. Another way is to perform *posterior predictive simulation*. In posterior predictive simulation, we use the posterior distribution to generate new samples while controlling the values of predictors to see what we would expect to happen if the experiment or observations were performed again.

Step 4: Model comparison

Model comparison involves evaluating which model(s) has/have the greatest predictive utility. If we are using all of the data to build our models, model comparison typically takes on the form of cross-validation. Specifically, we iteratively hold out pieces of the data and predict on these held out pieces (Vehtari et al., 2017).¹³ Model comparison implicitly applies the

¹³ This contrasts with the machine learning tradition of building the model on a training set and evaluating performance on a held-out test set.

principle of parsimony or Occam's Razor – weeding out overly complex models that fit well to sample data but are unlikely to perform well on unseen data (MacKay, 1992). Unlike Frequentist model comparison which is typically all-or-none, Bayesian model comparison is more nuanced. For example, it could indicate that two models perform equally well, or that one model is only somewhat better than another.

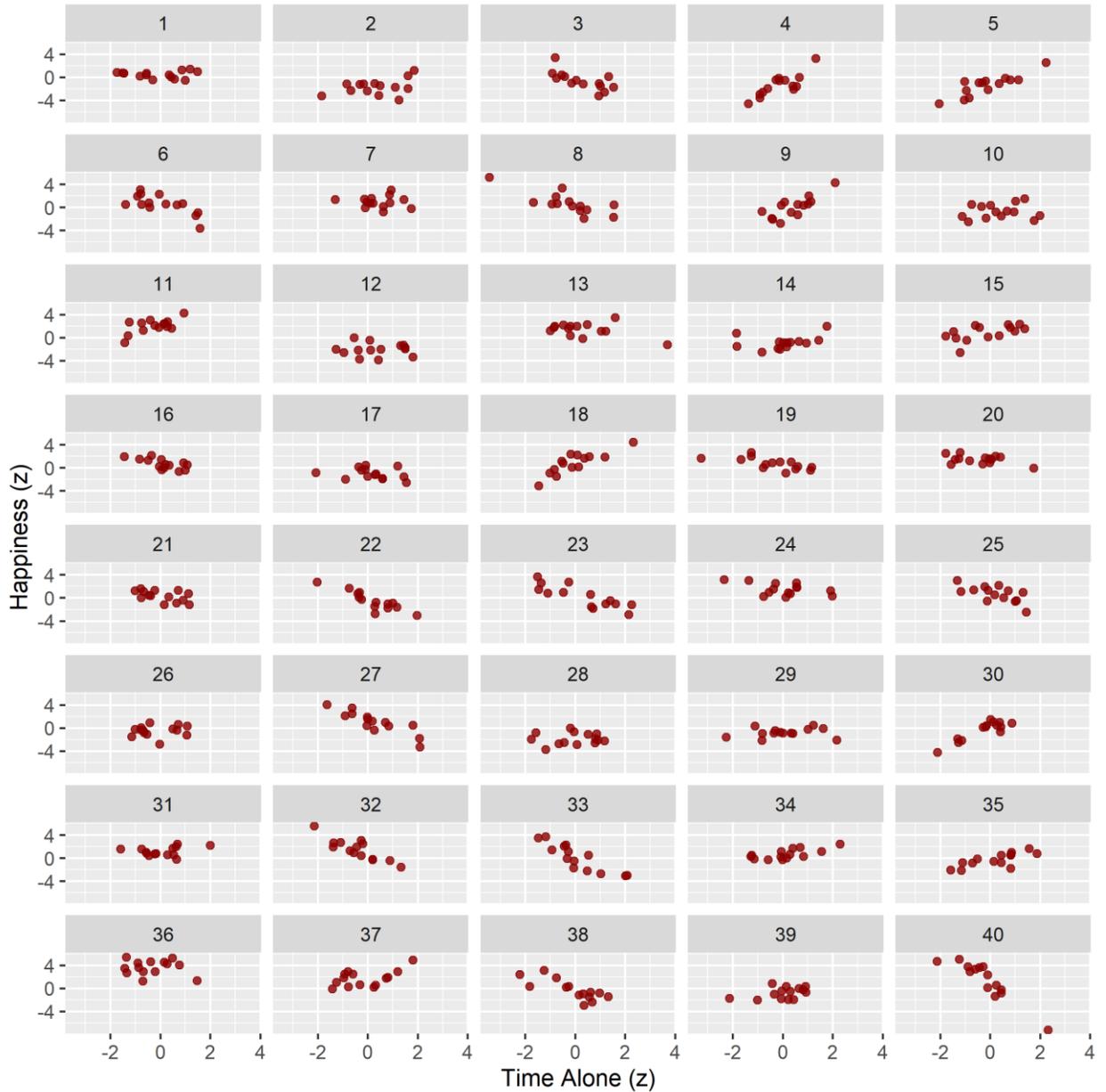
Comparing Frequentist and Bayesian Designs: A Practical Example

To see Bayesian statistics in action and compare it with the more traditional Frequentist paradigm, we use a toy example – simulated data. Let us imagine that we have data on hours spent alone per day and happiness from $N = 40$ participants over $J = 14$ days. We want to infer the relation between hours spent alone and happiness, but we recognize that there may be systematic variance *within* participants. Therefore, we want a model that can identify the overall strength of the association between time alone and happiness (sometimes called the *fixed effect*), and the extent to which this varies among participants (sometimes called the *random effects*).

We simulate data to have the following characteristics:

- Small population slope (fixed effect): -0.22
- Correlation between participant intercept and slope: -0.15
- Large variance in participant-level intercepts and slopes: 1 and 1

Figure 1 shows each simulated participant. For some participants there is a clear negative association between hours spent alone and happiness (e.g., #27), for others the association seems to be positive (e.g., #4), and still among other participants there is no discernible association (e.g., #12).

Figure 4. Simulated Data from $N = 40$ Simulated Participants.

Notes: Each window shows Time Alone and Happiness data for one simulated participant and each point shows one response from that simulated participant. Variables are z-score standardized.

We now compare a Frequentist and Bayesian approach to modelling this data. For each, we first execute a varying intercepts model of the form:¹⁴

$$\begin{aligned} y_i &\sim \text{Normal}(\mu_i, \sigma) \\ \mu_i &= \alpha + \delta_j + \beta x_i \end{aligned} \tag{2}$$

The response variable, y_i , is happiness for observation i . We assume y_i is drawn from a normal distribution with mean μ_i and a population standard deviation σ . In the definition for μ_i , α is a population intercept and β is a population slope multiplied by a participant-specified time alone score x_i . There is also a participant-specific random intercept denoted by δ_j . We can think of this term as shifting each participant from the population by a degree of δ_j .

We then estimate a varying slopes model of the form:

$$\begin{aligned} y_i &\sim \text{Normal}(\mu_i, \sigma) \\ \mu_i &= \alpha + \delta_j + (\beta + \omega_j)x_i \end{aligned} \tag{3}$$

Where we add a participant-specific slope term ω_j . Think of ω_j as adding a nudge to the population slope β for each participant.

Frequentist Approach

To fit this model using a Frequentist approach, we use maximum likelihood estimation (ML) to derive each of the parameters in Equation 2. We use the R package *lme4* (Bates et al., 2015) to fit the model. Model coefficients are presented in Table 2. For the varying intercepts model, ML estimates the population slope to be $\beta = -0.205$, which is close to the true population

¹⁴ A note on notation: \sim is read as *distributed as* and is used in the context of assigning parameters (and their priors) to probability distributions. $=$ implies a deterministic relationship.

value of -0.22 and is significant at $p = 0.001$. It also estimates the variance among the participant intercepts to be 1.338, which is somewhat higher than the true value of 1.

For the varying slopes model, ML estimates the population slope to be -0.147, but it is much less certain about the estimate and it is no longer significant: $p = 0.374$. As for the random effects, the participant variance in intercepts is roughly the same as in the previous model. We now have a term of variance in participant slopes, which ML estimates as 0.982, close to the true value of 1. We also have an estimate of the correlation between participant intercepts and slopes, which in this model is estimated at -0.143, close to the true population correlation of -0.15.

Table 1. Results from Maximum Likelihood and Bayesian Estimation

Maximum Likelihood Estimation					
Parameter	Estimate	SE/SD	95% CI		<i>p</i>
			LL	UL	
1. Varying Intercepts					
Fixed Effects					
		SE			
Intercept	0.266	0.192	-0.110	0.642	0.173
Time Alone	-0.205	0.061	-0.325	-0.085	0.001
Random Effects					
		SD			
Intercept	1.338	1.157	-	-	-
2. Varying Slopes					
Fixed Effects					
		SE			
Intercept	0.272	0.189	-0.098	0.642	0.157
Time Alone	-0.147	0.163	-0.466	0.172	0.374
Random Effects					
		SD			
Intercept	1.347	1.161	-	-	-
Slope	0.982	0.991	-	-	-
Correlation	-0.143	-	-	-	-
Bayesian Estimation (Regularizing Priors)					
Parameter	Estimate	SD	95% CI		
			LL	UL	
1. Varying Intercepts					
Fixed Effects					
Intercept	0.256	0.166	-0.062	0.573	-
Time Alone	-0.208	0.061	-0.329	-0.089	-
Random Effects					
Intercept	0.999	1.008	0.940	1.070	-
2. Varying Slopes					
Fixed Effects					
Intercept	0.249	0.184	-0.105	0.614	-
Time Alone	-0.152	0.161	-0.492	0.158	-
Random Effects					
Intercept	1.004	0.032	0.943	1.069	-
Slope	0.981	0.022	0.921	1.000	-
Correlation	-0.125	0.144	-0.389	0.161	-
Bayesian Estimation (Vague Priors)					
95% CI					

Parameter	Estimate	SD	LL	UL	
1. Varying Intercepts					
Fixed Effects					
Intercept	0.267	0.168	-0.067	0.593	-
Time Alone	-0.209	0.060	-0.330	-0.094	-
Random Effects					
Intercept	1.018	1.028	0.022	3.723	-
2. Varying Slopes					
Fixed Effects					
Intercept	0.292	0.192	-0.097	0.669	-
Time Alone	-0.148	0.167	-0.470	0.194	-
Random Effects					
Intercept	1.197	0.143	0.948	1.522	-
Slope	1.015	0.130	0.798	1.298	-
Correlation	-0.133	0.153	-0.419	0.178	-

Notes: Results are from simulated data. CI refers to confidence interval in the Frequentist setting and credible interval in the Bayesian setting.

We perform model comparison to determine whether modelling varying slopes helps to explain more of the variability in the outcome. Model comparison for ML is shown in Table 2. All criteria (AIC, BIC, Log-likelihood) point to the varying slopes model outperforming the simpler varying intercepts model. We would then conclude that there is no relation between time alone and happiness because the β coefficient in the varying slopes model is not significant. We would conclude, however, that there is substantial variability among participants in terms of their intercept and slope for the relation between time alone and happiness.

Table 2. Frequentist Model Comparison

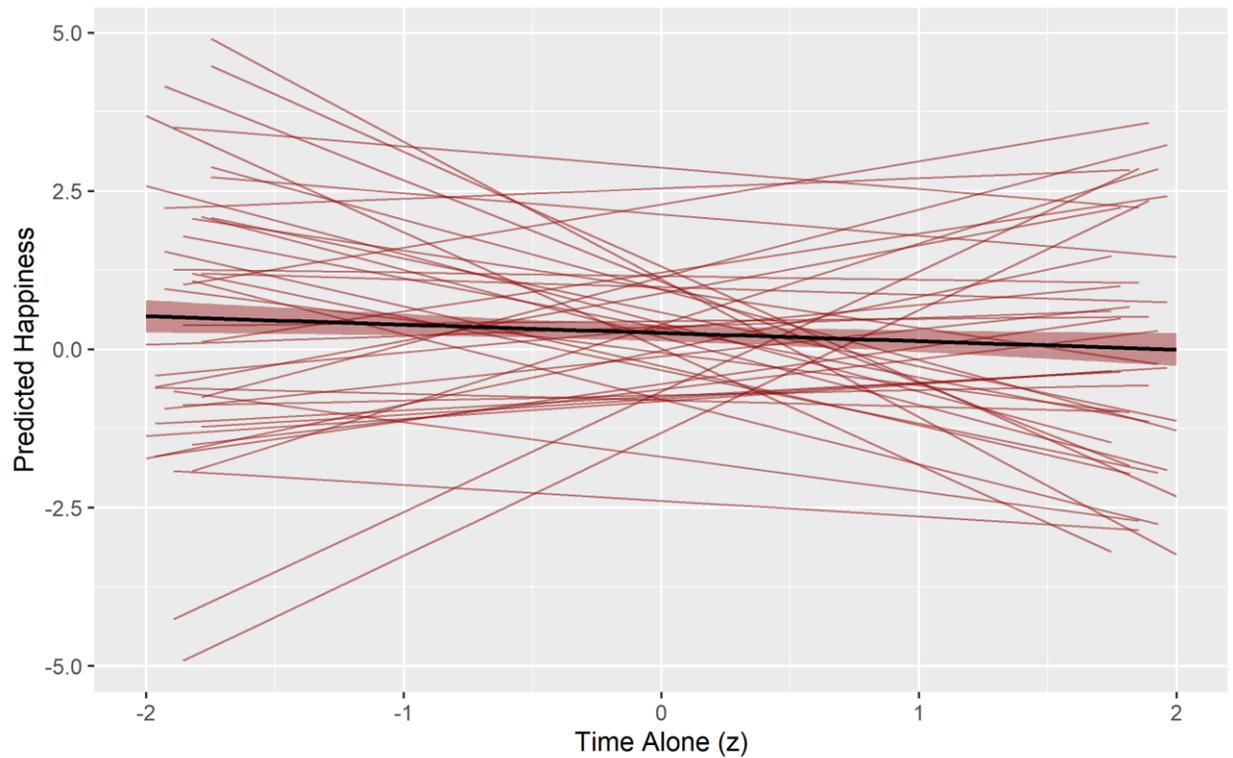
Model	AIC	BIC	Log-lik	p (d log-lik)
Varying Intercepts	2056.4	2073.7	-1024.20	NA
Varying Slopes	1821.9	1847.9	-904.95	< 0.001

Notes: Results are from simulated data. AIC = Akaike Information Criteria; BIC = Bayesian Information Criteria; Log-lik = Log-likelihood; p (d log-lik) = p -value for difference in log-likelihood.

Visualizing model predictions

We generate model-implied predictions to visualize the estimated population slope relative to the variability in participant slopes (see Figure 5). Notice how the ML estimate for the slope is basically flat relative to the participant-level slopes, which vary widely.

Figure 5. Model-implied predictions for varying slopes model using maximum likelihood estimation (Frequentist).



Notes: Black line is ML estimate of the fixed slope, red shaded region is the 95% confidence band corresponding to the fixed slope. Red lines are predicted trends for each of the $N = 40$ simulated participants.

Bayesian Approach

The main practical difference with the Bayesian approach is the addition of priors for each of our model parameters. To demonstrate how the results differ depending on the choice of prior, we will explore two types of priors: regularizing and vague priors. Regularizing priors constrain values to be less extreme – an example would be a normal distribution with mean 0 and standard deviation 1 – which helps to avoid overfitting. Vague priors allocate probability more evenly, allowing for more extreme values – an example would be a normal distribution with mean 0 and standard deviation 10. Only the model with the regularizing priors is interpreted here, but the vague prior version is shown for comparison.

Interpretation of model coefficients

Table 1 shows the mean posterior distributions and 95% credible intervals for the model parameters. For the varying intercepts model, the Bayesian mean for β is -0.208, which is nearly identical to the ML estimate and the true population parameter. In contrast to the ML model, the Bayesian mean for the variance in participant intercepts is much closer to the true population parameter (Bayesian = 0.999, ML = 1.338, true = 1). For the varying slopes model, the Bayesian mean for β is -0.153 (contrast this with the true = -0.22 and the ML estimate = -0.147). The variance in participant intercepts and slopes is similar to the ML estimate. The correlation among participant intercepts and slopes is estimated at -0.121. With vague priors, the estimates are nearly identical – only a few are slightly more extreme due to less restrictive prior. This is important because it shows that a large alteration to the prior still has minimal impact when there is enough data.

Model comparison

With our models now generated and their implied distributions explored, we want to compare them to see whether increasing complexity pays off in terms of greater explanatory power. In other words, does adding more covariates such as extraversion and emotion regulation strategies help to model affect, or are we better off with less complex models?

There are two commonly used indices for comparing model fit: Watanabe-Akaike Information Criterion (WAIC; Watanabe, 2010) and Leave One-Out (LOO) cross validation (Vehtari et al., 2017). Similar to its predecessor AIC, WAIC estimates out-of-sample fit by determining the amount of information loss in a given model, which can be used to compare across other models. In contrast, LOO estimates out-of-sample fit by examining the model's predictive accuracy across repeated samples with a single data point omitted. The *loo* package in R (Vehtari et al., 2017) provides a computationally efficient estimate of LOO using pareto-smoothed importance sampling (i.e., gearing cross-validation toward influential data points). Better fitting models are indicated by lower WAIC and LOO values and weight assignment closer to 1. Weight is provided by McElreath's (2020) *rethinking* R package. It accumulates information across WAIC and LOO to give a comparative assessment of how predictive each model is.¹⁵

A summary of model comparison indices for the simulated data is provided in Table 3. Notice that the varying slopes model is superior to the varying intercepts model on all counts. This is consistent with the model comparison the ML context.

¹⁵ See <https://github.com/rmcelreath/rethinking> for more information.

Table 3. Bayesian Model Comparison

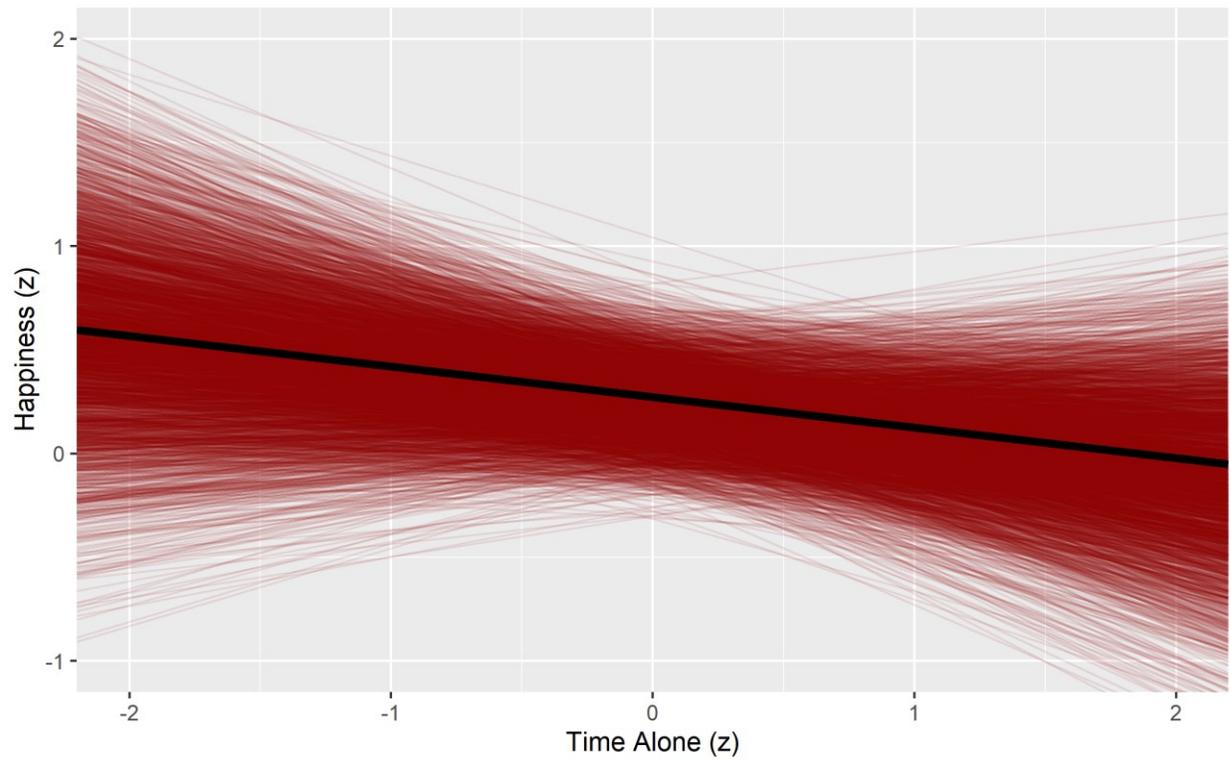
Model	WAIC (SE)	LOO	Weight
Varying Intercepts	1997.4 (41.05)	-998.9	0
Varying Slopes	1673.0 (33.00)	-839.3	1

Notes: Results are based on simulated data. WAIC (SE) = Watanabe-Akaike Information Criteria and its corresponding standard error; LOO = Leave-One-Out cross validation; Weight = how much credibility to allocate to a model (1 = maximum credibility).

Visualizing and simulating from the posterior

As with the ML example, we desire some way to visualize the model predictions and their uncertainty. In Bayesian statistics, there are a few ways to accomplish this. One way is to plot samples from the posterior distribution. Recall that the posterior distribution is a collection of samples, where each sample is a plausible realization of the model parameters. In looking at these samples, we get a sense of how the parameters are distributed. Figure 6 shows draws from the posterior distribution for the fixed intercept and fixed slope of the varying slopes model. Each line is a plausible regression line for the model.

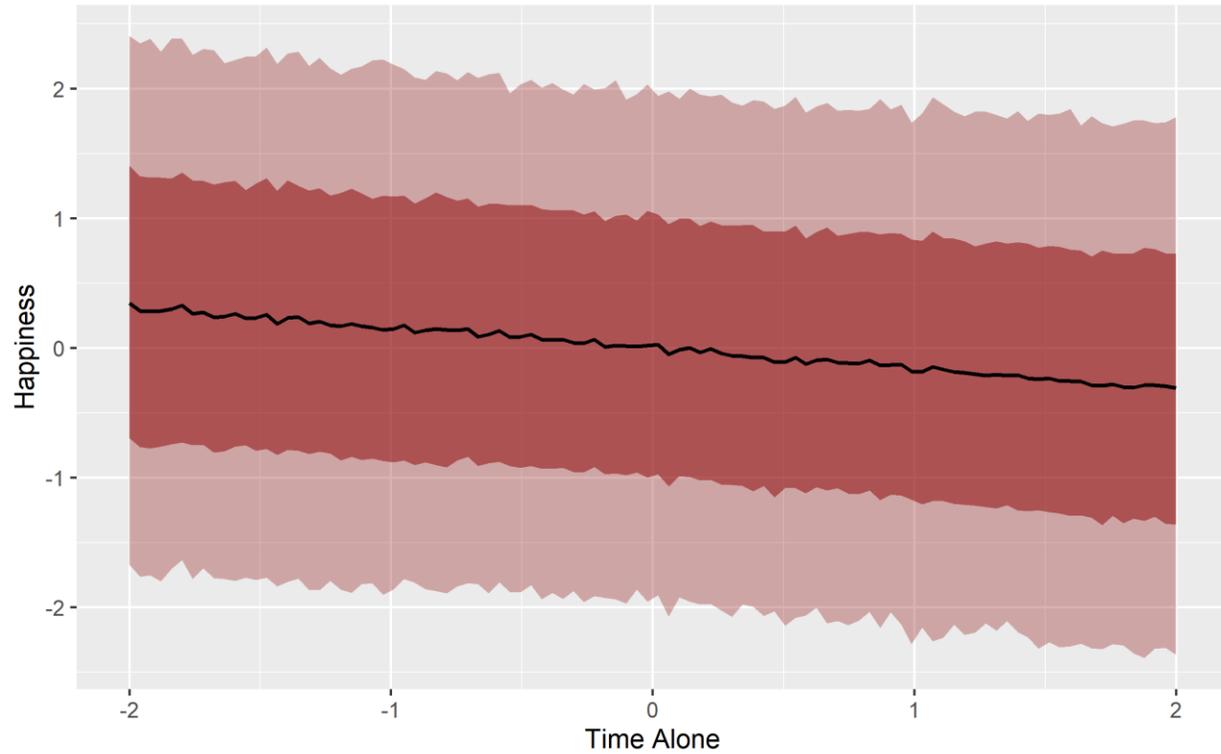
Figure 6. Visualizing the posterior predictive distribution of the fixed regression intercept and slope.



Notes: Black line is the mean posterior regression line. Each red line is a draw from the posterior distribution. Thus, each line is a plausible regression line given the data and prior information.

A second approach is to simulate new predictions from the posterior distribution. This is called posterior predictive simulation, and it is key to understanding what kind of scenarios that model would “expect” from unseen data. This is shown in Figure 7. For each value of Time Alone ranging from -2 to 2, we simulate happiness and then summarize the results in the form of 68% and 95% credible intervals. As in the ML case, the fixed slope is quite flat due to the large amount of participant variance.

Figure 7. Posterior Predictive Simulation



Notes: We simulate 4,000 values of Happiness based on the model coefficients. Black line is the mean estimate, dark red region is the 68% credible interval, and the light red region is the 95% credible interval. Note that the jagged appearance is due to the randomness of the simulation.

In summary, both maximum likelihood (Frequentist) and Bayesian approaches produced parameter estimates close to the true population parameter values, suggesting minimal practical differences in choosing Frequentist versus Bayesian estimation. Indeed, this is not surprising and is actually encouraging when considering the structure of the problem. In both the Frequentist and Bayesian setting, minimal prior knowledge of the parameter values was assumed. This assumption is implicit in the Frequentist setting but was *made explicit* in the Bayesian scenario in the form of regularizing priors (weakly regularizing in the first example and vague priors in the second). From an estimation standpoint, Bayesian statistics should only outperform maximum likelihood when there is a need to incorporate strong prior information (e.g., there is risk of overfitting due to small sample size or a desire to incorporate informative priors that bias estimates in a particular direction).

In this dissertation, the choice of Bayesian instead of Frequentist mostly comes down to a personal preference, which itself stems from the philosophical advantages of Bayesian statistics discussed earlier. However, there are models in this dissertation (see Study 3) which, due to their complexity, are likely to benefit from the Bayesian treatment.

Study 1: Solitude and Affect in Retrospective Emotional Events

The primary goal of Study 1 was to explore how being in a solitary versus a social context was associated with changes in valence and arousal in the aftermath of everyday positive and negative emotional events. A secondary goal was to explore other variables of interest as potential predictors. These included gender, extraversion, preference for solitude, and emotion regulation strategies. A third goal was to examine extraversion – not just as a predictor of Time 2 affect – but as a predictor of affect (e.g., Wilt et al., 2012).

Study 1 Hypotheses

- 1) Solitude will have a *deactivation* effect on arousal. In general, participants are expected to report a greater reduction in arousal for both negative and positive events when they are alone as compared to when they are with others (either with others and interacting or not interacting). There is no expected difference in the reduction of arousal between the conditions in which people are with others and interacting or with others and not interacting. The findings are expected to be more pronounced in the context of negative emotional events, yet we anticipate some deactivation effect for positive events.
- 2) Valence is expected to increase (or decrease less strongly) in contexts when people are with others and interacting – this is expected for both positive and negative events. There is no expected difference in change in valence between the alone and with others not interacting conditions. In other words, interacting with others is expected to increase valence compared to the other two contexts.
- 3) Trait extraversion will be negatively associated with a deactivation effect of solitude, consistent with the popular yet largely untested idea that introverts seek solitude to help calm down (Cain, 2012). It is expected that this will particularly be the case for negative events, as introverts may be more likely to want to be alone to reduce *negative* emotions, like stress and anxiety. Preference for solitude is expected to be positively associated with deactivation, as those who enjoy solitude may find it more calming and enjoyable.
- 4) Preference for solitude will be associated with changes in valence during solitude. Specifically, preference for solitude will be positively associated with valence while alone. This is anticipated because preference for solitude has been previously associated with more positive solitary experiences (Chua & Koestner, 2008; Nguyen et al., 2018,

- 2019). Those who intrinsically enjoy solitude are more likely to use their time alone productively engaged in activities that are rewarding and meaningful, therefore bolstering positive affect during solitude (Larson, 1990; Leary et al., 2003).
- 5) The use of emotion regulation strategies (e.g., distraction, reappraisal) will be differentially associated with change in emotions. Specifically, distraction and reappraisal should be positively associated with valence, whereas suppression and rumination should be negatively associated with valence (Aldao et al., 2010; Webb et al., 2012). These are tentative hypotheses because recent research has called into question the one-to-one link between strategy and well-being, instead advocating for a more nuanced *flexible* regulation approach (Bonanno & Burton, 2013).
- 6) There are no hypothesized effects of gender in either change in arousal or valence. It is also not expected that gender would moderate associations between extraversion and preference for solitude in change in affect. Nevertheless, gender is included as a control variable in all analyses.
- 7) Those higher in extraversion will be more likely to interact with others (compared to being alone or with others and not interacting) following an emotional event. There is extensive evidence linking extraversion to an increase in social interaction (e.g., Tellegen, 1985).

Study 1 Method

Participants and Procedure

Data for Study 1 was collected during the Fall semester of 2018. A sample of $N = 663$ university undergraduate students (419 Female, 235 Male, 4 Other, 3 Prefer to not answer) ranging from 16 to 52 years of age ($M = 19.82$, $SD = 4.00$) attending first- and second-year

Psychology courses at Carleton University completed the online survey for course credit. The majority of participants were White (54.30%), followed by Asian (18.55%), Other (14.78%), African-Canadian (7.24%), Hispanic (1.51%), and Aboriginal (1.21%).

All procedures were approved by the Carleton University Research Ethics Board-B (CUREB-B). The online survey was designed to take approximately 30 minutes to complete, though many participants finished in less time. All participants first received demographic questionnaires (e.g., sex, age, and ethnicity) followed by retrospective report of emotional events. The remaining questionnaires were received in randomized order.

Measures

Gender.

Gender was dummy coded into four categories: Female, Male, Gender NB (non-binary) and Gender NA (prefer to not answer or missing). Despite the latter two categories having substantially lower counts than the former two, they are still included in the models because: (1) it would be unethical to drop or combine them, and (2) the use of priors allows us to include categories with low counts without running into issues surrounding identifiability.

Trait emotion regulation strategy use.

Measures of trait emotion regulation strategy use were included for validation purposes. In other words, these are not included in subsequent descriptive or inferential analyses for the purpose of succinctness. We used the following measures as trait emotion regulation strategy use: *reappraisal* and *suppression* subscales from the Emotion Regulation Questionnaire (Gross & John, 2003), *ruminative responses* from the Ruminative Responses Scale (Nolen-Hoeksema et al., 1999), *stress* from the Perceived Stress Scale (Cohen et al., 1994), *positive refocusing* from the Cognitive Emotion Regulation Questionnaire (Garnefski et al., 2002), and *co-rumination* from

the Co-Rumination Questionnaire (Rose, 2002). Note that in some cases these trait measures do not map perfectly onto their state counterparts and instead are only conceptually similar (e.g., distraction and positive refocusing).

Retrospective recall of emotional events.

Methodology for assessing change in emotion from Time 1 to Time 2 (one hour following the event) and use of emotion regulation strategies was adapted from Brans et al. (2013, see also Troy et al., 2018), who used this method over a series of experience sampling days. In the current study, participants were asked to recall one positive and one negative event (presented in random order) that took place in the past 24 hours.¹⁶ To aid in recall, participants were presented with a pictorial timeline representing the time leading up to and following the event (see Appendix A). For each event, participants reported on their valence and arousal when the event took place and again one hour following the event. Valence was assessed on a 7-point scale (1 = extremely unpleasant, 7 = extremely pleasant) as was arousal (defined as “awake, alert, or activated”; 1 = extremely low arousal, 7 = extremely high arousal).

Participants then completed a series of questions about the time following the event up to an hour after. They indicated whether they were alone, with others and interacting, or with others and not interacting during most of the time. These three options were chosen because they capture different definitions of solitude and social interaction (e.g., solitude as physical vs. social separation) (Larson, 1990; 2002).

For each event, participants also reported on their use of six strategies each assessed with one item rated on a five-point scale (1 = not at all, 5 = a lot). The items, adapted by Brans et al. (2013) captured the following strategies: *reflection* (“I calmly reflected on my feelings”),

¹⁶ If nothing negative or positive took place during this time, participants were asked to think back to the most recent event that week.

reappraisal (“I changed the way I think about what caused my feelings”), *ruminat*ion (“I couldn’t stop thinking about my feelings”), *suppression* (“Avoided expressing my feelings”), *distraction* (“Engaged in activities to distract myself from my feelings”), and *social support* (“I have talked about my feelings with others”). These items were previously found to correlate strongly with trait measures of emotion regulation and demonstrated reasonable within-person reliability (Blanke et al., 2019; Brans et al., 2013; Troy et al., 2018).

In the current study, there were modest correlations between trait and state emotion regulation: trait and state reappraisal $r = 0.189$; trait and state suppression $r = 0.403$; trait positive refocusing and state distraction $r = 0.130$; trait rumination and state rumination $r = 0.380$; trait stress and state reflection $r = 0.171$; trait co-rumination and state social support $r = 0.312$. Note that in some cases there is less than perfect conceptual correspondence between the trait and state measure of the strategy.

Preference for solitude.

Preference for solitude was assessed using nine items from the Preference for Solitude scale adapted by Burger (1995) and Lee (2013). The original scale developed by Burger (1995) scored items dichotomously. We subsequently transformed them to be assessed on an ordinal scale to allow for intermediate responses (1 = strongly disagree, 7 = strongly agree) (see Coplan, Hipson, et al., 2019 for more details). Positive scores reflect general enjoyment of time spent alone (“Time spent alone is often productive for me”), whereas negative scores reflect solitude aversion (“Time spent alone is often boring and uninteresting”). Three items from the original 12-item scale were removed because they focused on travelling to get away, which is probably less relevant to emerging adults. We found this adapted version to have good internal

consistency (Cronbach's $\alpha = 0.88$, in the current study), and in previous studies it converged with measures of time spent alone and affinity for aloneness (Coplan, Hipson, et al., 2019).

Extraversion.

As a measure of extraversion, participants completed the 8-item extraversion subscale of the *Big Five Inventory* (John & Srivastava, 1999). Items were rated on a 5-point scale (1 = disagree strongly, 5 = agree strongly) pertaining to stable behaviours reflecting introversion-extraversion (e.g., "Is full of energy", "Is sometimes shy, inhibited" *reverse-scored*). This measure has demonstrated adequate internal consistencies in student and community samples (Cronbach's $\alpha = .61-.88$), correlates with other measures of personality, and is predictive of well-being and psychopathology (Soto & John, 2009). In the current study, Cronbach's alpha was 0.82.

Data Preparation and Cleaning

Data preparation involved computing mean summary scores from individual subscale items. Any participant missing data on at least one third of individual items of a subscale was immediately scored as 'missing' on that subscale. Data cleaning steps included (1) excluding 19 participants for completing the survey too quickly (less than five minutes), (2) removing 17 multivariate outliers, and (3) dealing with missing data. We used Mahalanobis distance with a $\chi^2(\alpha = .001)$ cut-off to identify multivariate outliers from all study variables.

Upon removing problematic and outlying data, missing data was extremely rare. There was less than 1% missing across variables in the retrospective reports and roughly 3.5% missing on trait extraversion and introversion. The low proportion of missing notwithstanding, it is still advisable to include participants with missing data. We had no reason to suspect that data were systematically missing, so we used Bayesian imputation for imputing missing data (Gelman et

al., 2013). Bayesian imputation involves treating missing data as unknown parameters and estimating them just as we would with a regression intercept or slope parameter. These estimates are then fed into the model so that the information can be used to estimate the model itself.

Study 1 Results

Descriptive Statistics

Descriptive statistics for continuous variables in Study 1 are presented in Table 1. Of note, we see that valence tends to increase for negative events and decrease for positive events, whereas arousal tends to decrease from Time 1 to Time 2. We also see that rumination has the highest average usage among emotion regulation strategies, followed by reflection, social support, distraction, suppression, and reappraisal.

For negative events, 48.33% of people reported being alone, 26.32% reported being with others and interacting, and 24.72% reported being with others but not interacting. In contrast, for positive events, 27.82% were alone, 52.00% were with others and interacting, and 19.46% were with others but not interacting. This stark asymmetry in the proportion of social context among different types of events is important to keep in mind when interpreting subsequent analyses.

Table 4. Descriptive statistics for continuous variables in Study 1.

Negative Events					Positive Events				
	Mean	SD	Min	Max		Mean	SD	Min	Max
t1 Valence	2.04	1.15	1.00	7.00	t1 Valence	6.15	1.28	1.00	7.00
t1 Arousal	4.21	1.90	1.00	7.00	t1 Arousal	5.55	1.34	1.00	7.00
t2 Valence	2.86	1.51	1.00	7.00	t2 Valence	5.58	1.26	1.00	7.00
t2 Arousal	3.69	1.66	1.00	7.00	t2 Arousal	4.91	1.40	1.00	7.00
Pref. Solitude	4.47	1.13	1.11	7.00	Pref. Solitude	4.47	1.13	1.11	7.00
Extraversion	3.08	0.77	1.00	5.00	Extraversion	3.08	0.77	1.00	5.00
Reflection	2.64	1.27	1.00	5.00	Reflection	2.80	1.28	1.00	5.00
Reappraisal	2.37	1.23	1.00	5.00	Reappraisal	2.25	1.22	1.00	5.00
Rumination	3.20	1.39	1.00	5.00	Rumination	2.55	1.36	1.00	5.00
Suppression	2.80	1.40	1.00	5.00	Suppression	1.98	1.19	1.00	5.00
Distraction	2.99	1.42	1.00	5.00	Distraction	1.96	1.24	1.00	5.00
Soc. Support	2.36	1.37	1.00	5.00	Soc. Support	2.67	1.39	1.00	5.00

Correlation coefficients for continuous variables are presented in Table 5 (for negative events) and 6 (positive events). p -values are presented for descriptive purposes. It is worth noting the strong correlation between valence and arousal.

Table 5. Pairwise correlation coefficients for all continuous variables in Study 1 (negative events).

Negative Events											
	t1 Valence	t1 Arousal	t2 Valence	t2 Arousal	Pref. Solitude	Extraversion	Reflection	Reappraisal	Rumination	Suppression	Distraction
t1 Valence	-	-	-	-	-	-	-	-	-	-	-
t1 Arousal	0	-	-	-	-	-	-	-	-	-	-
t2 Valence	0.38***	0.01	-	-	-	-	-	-	-	-	-
t2 Arousal	0.08*	0.51***	0.18***	-	-	-	-	-	-	-	-
Pref. Solitude	-0.03	0.08*	-0.01	0.04	-	-	-	-	-	-	-
Extraversion	-0.02	-0.11**	-0.04	-0.01	-0.35***	-	-	-	-	-	-
Reflection	0.06	0.01	-0.04	-0.06	0.1*	0.07	-	-	-	-	-
Reappraisal	0.03	-0.02	-0.05	-0.03	0.1*	0.04	0.46***	-	-	-	-
Rumination	-0.18***	0.08*	-0.29***	-0.08*	0.1*	-0.05	0.28***	0.25***	-	-	-
Suppression	-0.02	-0.06	-0.16***	-0.08*	0.14***	-0.12**	0.14***	0.14***	0.33***	-	-
Distraction	-0.01	0.04	-0.09*	0	0.06	0.02	0.21***	0.16***	0.26***	0.36***	-
Soc. Support	0	0.06	-0.01	0.03	-0.04	0.19***	0.17***	0.23***	0.16***	-0.27***	0.01

Notes: *p*-values are presented for descriptive purposes. *** < 0.001, ** < 0.01, * < 0.05

Table 6. Pairwise correlation coefficients for continuous variables in Study 1 (positive events).

Positive Events												
	t1 Valence	t1 Arousal	t2 Valence	t2 Arousal	Pref. Solitude	Extraversion	Reflection	Reappraisal	Rumination	Suppression	Distraction	Soc. Support
t1 Valence	-	-	-	-	-	-	-	-	-	-	-	-
t1 Arousal	0.45***	-	-	-	-	-	-	-	-	-	-	-
t2 Valence	0.36***	0.29***	-	-	-	-	-	-	-	-	-	-
t2 Arousal	0.18***	0.4***	0.54***	-	-	-	-	-	-	-	-	-
Pref. Solitude	0.02	0.01	0.02	-0.03	-	-	-	-	-	-	-	-
Extraversion	0.05	0.07	0.18***	0.21***	-0.35***	-	-	-	-	-	-	-
Reflection	0.07	0.14***	0.18***	0.19***	0.09*	0.08*	-	-	-	-	-	-
Reappraisal	-0.08*	0.04	0.08*	0.14***	0.05	0.08*	0.51***	-	-	-	-	-
Rumination	0.09*	0.18***	0.13**	0.22***	0.04	0.08*	0.49***	0.42***	-	-	-	-
Suppression	-0.2***	-0.12**	-0.15***	-0.08*	0.1*	-0.11**	0.2***	0.35***	0.26***	-	-	-
Distraction	-0.24***	-0.09*	-0.18***	-0.07	0.08*	-0.09*	0.12**	0.37***	0.21***	0.57***	-	-
Soc. Support	0.07	0.18***	0.19***	0.22***	-0.02	0.13**	0.33***	0.28***	0.41***	-0.05	0.07	-

Notes: p -values are presented for descriptive purposes. *** < 0.001, ** < 0.01, * < 0.05

Study 1 Models Overview

Study 1 includes four models. Models 1.1, 1.2, and 1.3 focus on predicting affect at Time 2. Each of these three models increases in complexity with additional covariates. Model 1.4 is more exploratory and focuses on predicting social context (i.e., whether one is alone or with others). Together, these four models examine the plausibility of a deactivation effect of solitude as well as possible causal explanations for how social context and personality relate to our emotions.

Model 1.1: Social context, emotion context, and affect

The first goal was to examine how social context and event polarity predict affect at Time 2. The model is a multivariate regression model with two outcome variables: Time 2 valence and Time 2 arousal. The model controls for Time 1 affect as opposed to computing a difference score and using that as the outcome variable. The rationale behind this is Time 1 affect is not a controlled baseline and therefore can vary quite widely between participants. Computing a difference score ignores this initial variability which likely impacts the extent to which Time 2 affect differs from Time 1 (Kelly & Ye, 2016).

Mathematical model.

We model valence and arousal *jointly* rather than performing separate regressions. There are two reasons for choosing a multivariate model: (1) the theoretical model treats valence and arousal as two components within the larger affective system and thus it is sensible to model them jointly¹⁷, and (2) it is more parsimonious and economical (in an information theoretic

¹⁷ There is disagreement in the emotion literature as to whether valence and arousal should be viewed as orthogonal (independent) components. These factors were originally derived from principal components analysis and were consequently argued to be independent. More recent research suggests that valence and arousal form a U-shaped relationship (Kron et al., 2013).

sense) to include both outcomes in the same model.¹⁸ This type of model is called *seemingly unrelated regression* (SUR; Greene, 2011; Zellner, 1962) and it models multiple linear regressions with shared predictor variables and a covariance error structure. The mathematical structure of this model is shown in Equation 1:

$$\begin{aligned}
 & y_k \sim \text{Multinormal}(\mu, \Sigma) \\
 & \mu_k = x_i \beta_k \\
 & \beta_k \sim \text{Normal}(0, 5) \\
 & \Sigma = S \Omega S \\
 & S_k \sim \text{Exponential}(1) \\
 & \Omega \sim \text{LKJcorr}(4)
 \end{aligned}
 \tag{4}$$

In Equation 2, y is Time 2 affect and k denotes the dimension of affect. We state that each y_k is governed by a multivariate normal distribution with a mean vector μ and a covariance matrix Σ . The mean vector μ is determined by the model matrix x (containing the intercept and predictor variables) and the coefficient vector β . We then assign priors to the model parameters: β is given a Normal prior with mean 0 and standard deviation 5. The covariance matrix Σ is parameterized by a diagonal matrix S containing standard deviations for each k on the diagonal and a correlation matrix Ω . I have assigned the diagonal elements of S Exponential priors (because standard deviation cannot be negative) and Ω an LKJ Cholesky correlation prior (values greater than 1 are more skeptical of high correlations) (Lewandowski et al., 2009).

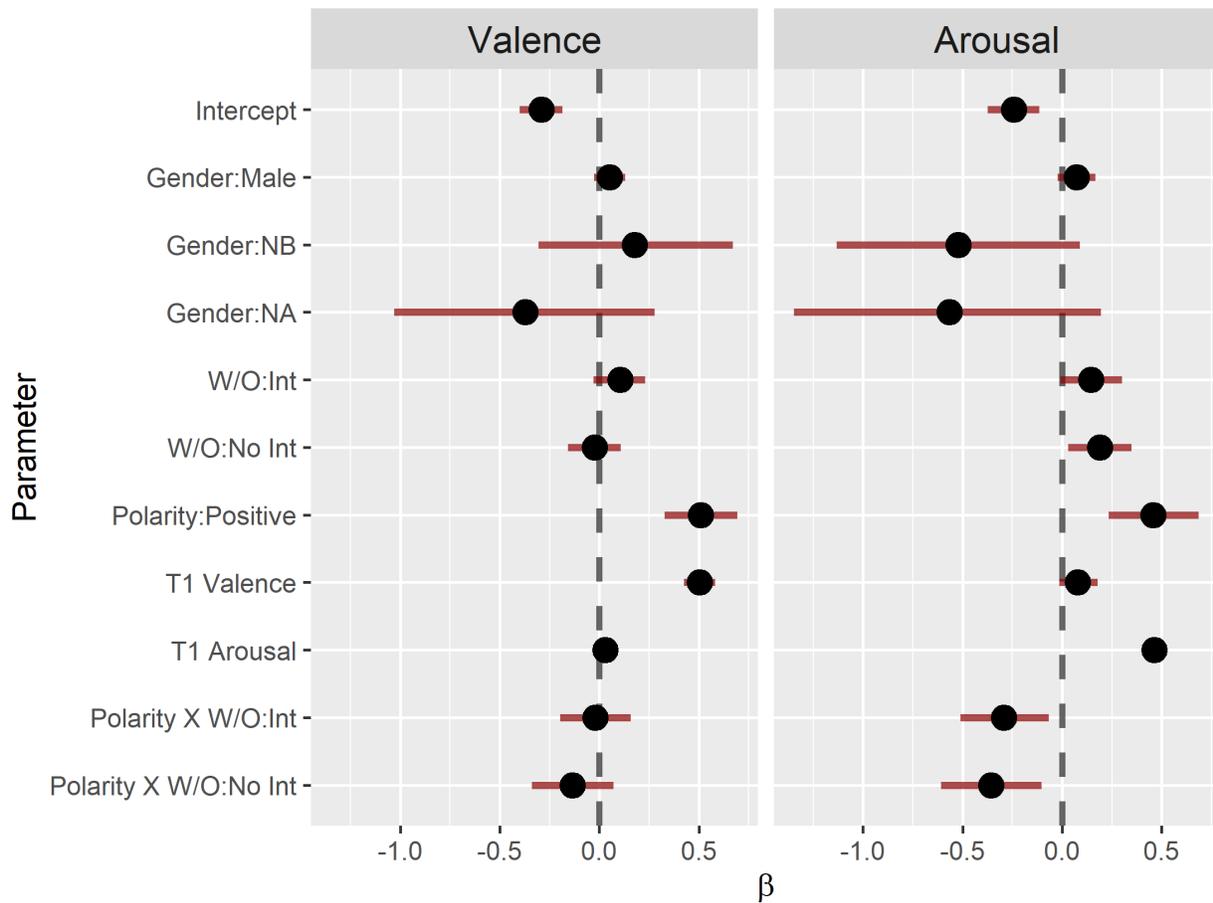
Coefficients for Model 1.1 are depicted in Figure 8 in the form of means and 95% credible intervals. The distribution of these parameters can generally be interpreted as the ‘effect’

¹⁸ This makes practical sense too. An ideal model structure to predict affect would model both jointly instead of separately.

of predictor on Time 2 affect controlling for Time 1 affect. Scores are standardized such that a value of 0 corresponds to no effect. Focusing our attention on arousal, we can see that being with others (interacting or not) appears to be associated with more Time 2 arousal compared to being alone (intercept). As well, positive events are associated with greater Time 2 arousal than negative events. Moreover, there appears to be an interaction between social context and event polarity. Specifically, among those who were alone and experiencing a negative event, arousal decreased, yet for those experiencing a positive event while alone arousal increased. However, there is much more uncertainty in the posterior for each of the interaction conditions, so we cannot say that the conditions are reliably different (i.e., there is substantial overlap in posterior density).

We note that there do not appear to be gender differences in change in affect. The coefficient for the dummy-code Male, is reliably at 0. Posterior distributions for the other two gender categories, are understandably wider. There is maybe some evidence that gender non-binary and NA reported decrease in arousal, but the credible interval is still quite wide and we should be cautious about drawing inferences from few observations.

Figure 8. Posterior distributions for Model 1.1 beta coefficients predicting Time 2 valence and arousal.



Notes: Black dots represent posterior means, red lines represent the 95% credible interval (i.e., the range of values containing 95% of the mass of the posterior distribution). Gender:NB = Gender: Non-binary; Gender:NA = Gender: Prefer to not answer; W/O: Int = With Others and Interacting; W/O: No Int = With Others and Not Interacting.

Posterior predictive simulation.

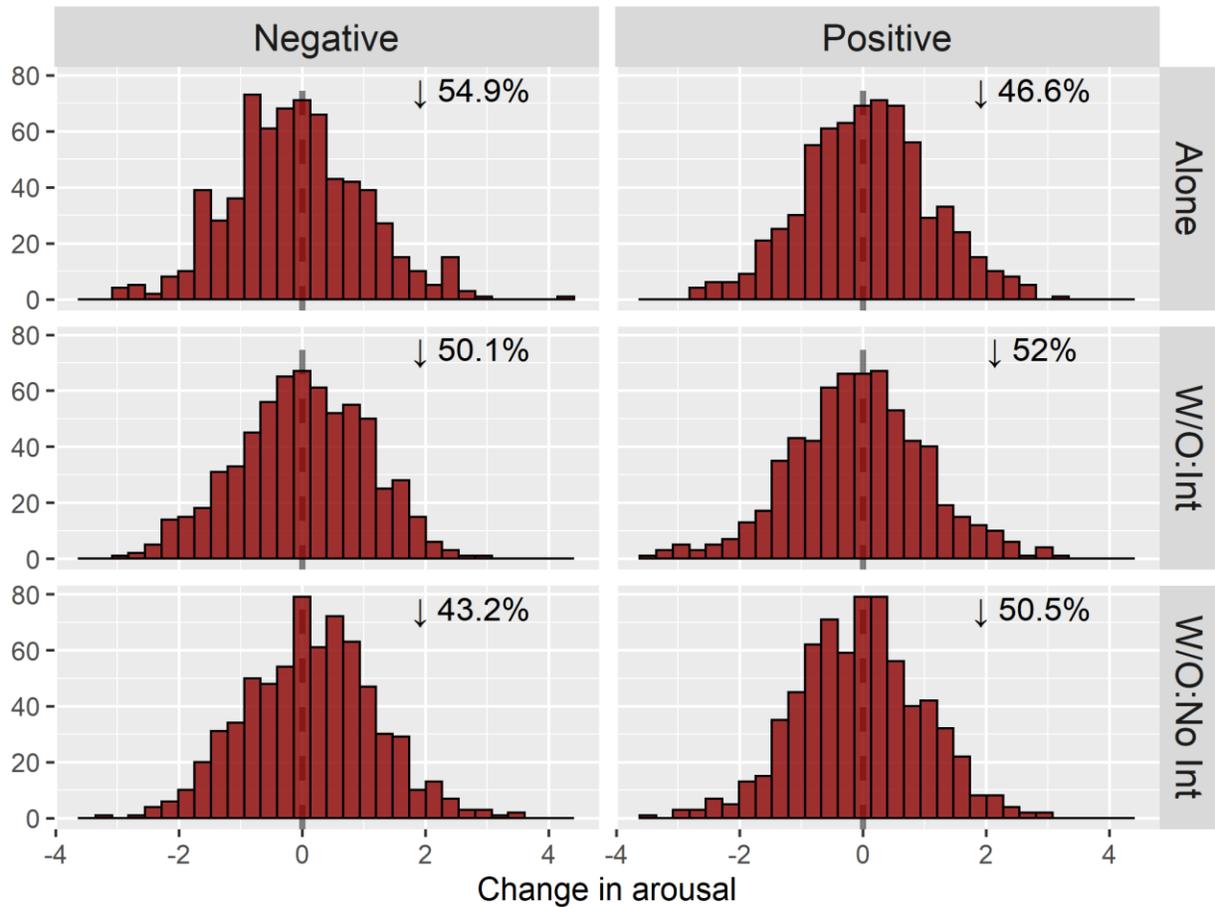
Arousal. We want to further focus on the potential effect of social context on change in arousal in order to evaluate the plausibility of a deactivation effect. Moreover, it seems we need to account for event polarity (i.e., is the event positive or negative?) as it appears to interact with social context. This meant performing posterior predictive simulation which involves sampling coefficients from the posterior distribution to predict the outcomes from simulated new data. This new data consisted of 4,000 “participants” with random initial conditions (i.e., randomly assigned to be any of the three social contexts and in any of the two events).

Figure 9 shows the results of this simulation. There is no obvious difference among the three social contexts, suggesting again that any effect of social context is relatively small and uncertain. Looking at the proportion of simulated participants whose arousal either increased or decreased, we can expect that being alone during a negative event results in a reduction of arousal 55% of the time, compared to the other social contexts where it is 50% and 43%, respectively. That being alone is only likely to result in a reduction of arousal 55% of the time (not even considering *how much* arousal is reduced by) does not inspire confidence of a huge deactivation effect. Indeed, the simulation suggests that we could hardly predict better than a coin flip as to whether someone who is alone will feel less arousal following a negative event. Relative to the other social contexts, however, this probability is somewhat larger, particularly when we contrast it against the context of With Others and Not Interacting in which we would only expect 43.2% of people’s arousal to decrease.

In contrast, for positive events, being alone seems to be the *least* likely context for reducing arousal – we only expect 46.6% of people’s arousal to drop in this context compared to 52% for with others and interacting, and 50.5% for with others and not interacting. This is in

direct contradiction of the deactivation effect as it would predict decreased arousal across negative and positive emotional events.

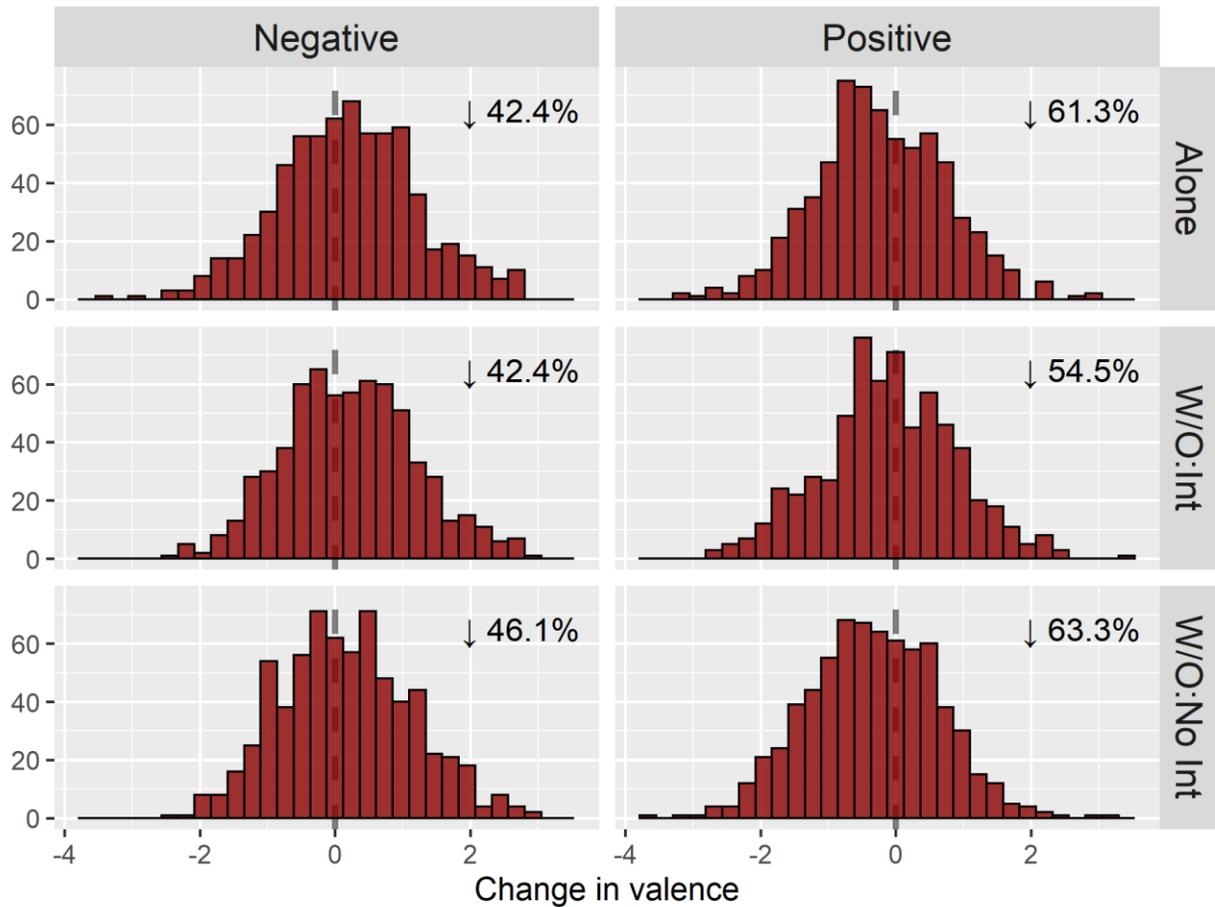
Figure 9. Histograms showing results of posterior predictive simulation using Model 1.1 parameters.



Notes: Percentages describe the proportion of simulated participants whose arousal decreased from Time 1 to 2 (i.e., percentage of simulated people where change in arousal is less than 0). Simulation of 4,000 “participants” randomly assigned to different conditions of Social Context and Event Polarity and with random initial affect.

Valence. Simulated results for valence are shown in Figure 10. Although not pertinent to the deactivation effect, there are some noteworthy differences among the various conditions. Whether people are alone or with others *and* interacting, valence is expected decrease 42.4% of the time following negative events, in contrast to 46.1% of the time when people are with others and not interacting. These probabilities are fairly similar and do not suggest a large difference in valence between social contexts for negative events. For positive events, valence is expected to decrease 61.3% when people are alone, which is similar to the 63.3% when people are with others and not interacting. However, when people are with others and interacting, valence is expected to decrease only 54.5% of the time. Thus, following a positive event, being with others and interacting is associated with an increased probability of valence increasing from Time 1 to Time 2 in contrast to the other social contexts.

Figure 10. Histograms showing results of posterior predictive simulation using Model 1.1 parameters.



Notes: Percentages describe the proportion of simulated participants whose valence decreased from Time 1 to 2 (i.e., percentage of simulated people where change in valence is less than 0). Simulation of 4,000 “participants” randomly assigned to different conditions of Social Context and Event Polarity and with random initial affect.

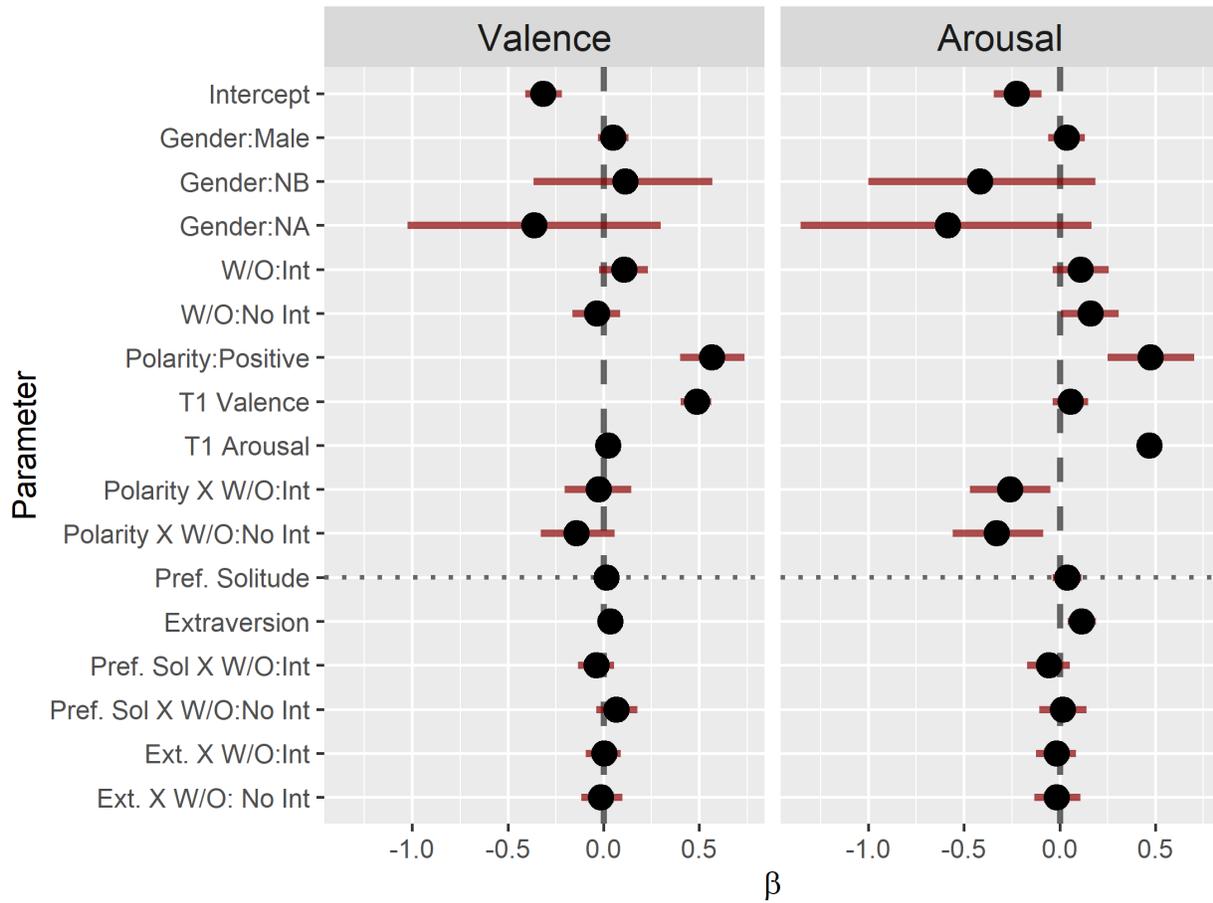
Model 1.1 Summary

The main conclusion from Model 1.1 is that there is evidence of a small deactivation effect, such that those who were alone reported lower arousal at Time 2 than those in the other two contexts. However, this deactivation is restricted to negative events and it is only evident in *contrast* to the other social contexts. In other words, we expect arousal would decrease in a solitary context only 55% of the time.

Model 1.2: Adding Preference for Solitude and Extraversion

In Model 1.2 we add trait-level characteristics, preference for solitude and extraversion, as well as their interaction with social context. The model structure is mathematically identical to Model 1.1 but with additional predictors. Coefficients for Model 1.2 are shown in Figure 11. These are largely unchanged compared to Model 1.1, the only minor difference being that extraversion is somewhat positively associated with greater Time 2 arousal. The posterior distributions for covariates entered in the previous model appear largely unchanged. Focusing our attention on main effects for preference for solitude and extraversion, the posterior distributions are quite certain and centered close to 0. Only does extraversion appear to have a minimal positive association with arousal, but the magnitude of this association (averaged at $\sim \beta = 0.1$) is small. The coefficients for the interactions among preference for solitude and extraversion with various social contexts all appear to hover around zero with a moderate degree of certainty. Therefore, we can be fairly confident that neither preference for solitude nor extraversion interact with social context to predict change in valence and arousal.

Figure 11. Posterior distributions for Model 1.2 beta coefficients predicting Time 2 valence and arousal.



Notes: Parameters on and below the dotted line are new to Model 1.2 (vs. 1.1). Black dots represent posterior means, red lines represent the 95% credible interval (i.e., the range of values containing 95% of the mass of the posterior distribution).

Model 1.2 Summary

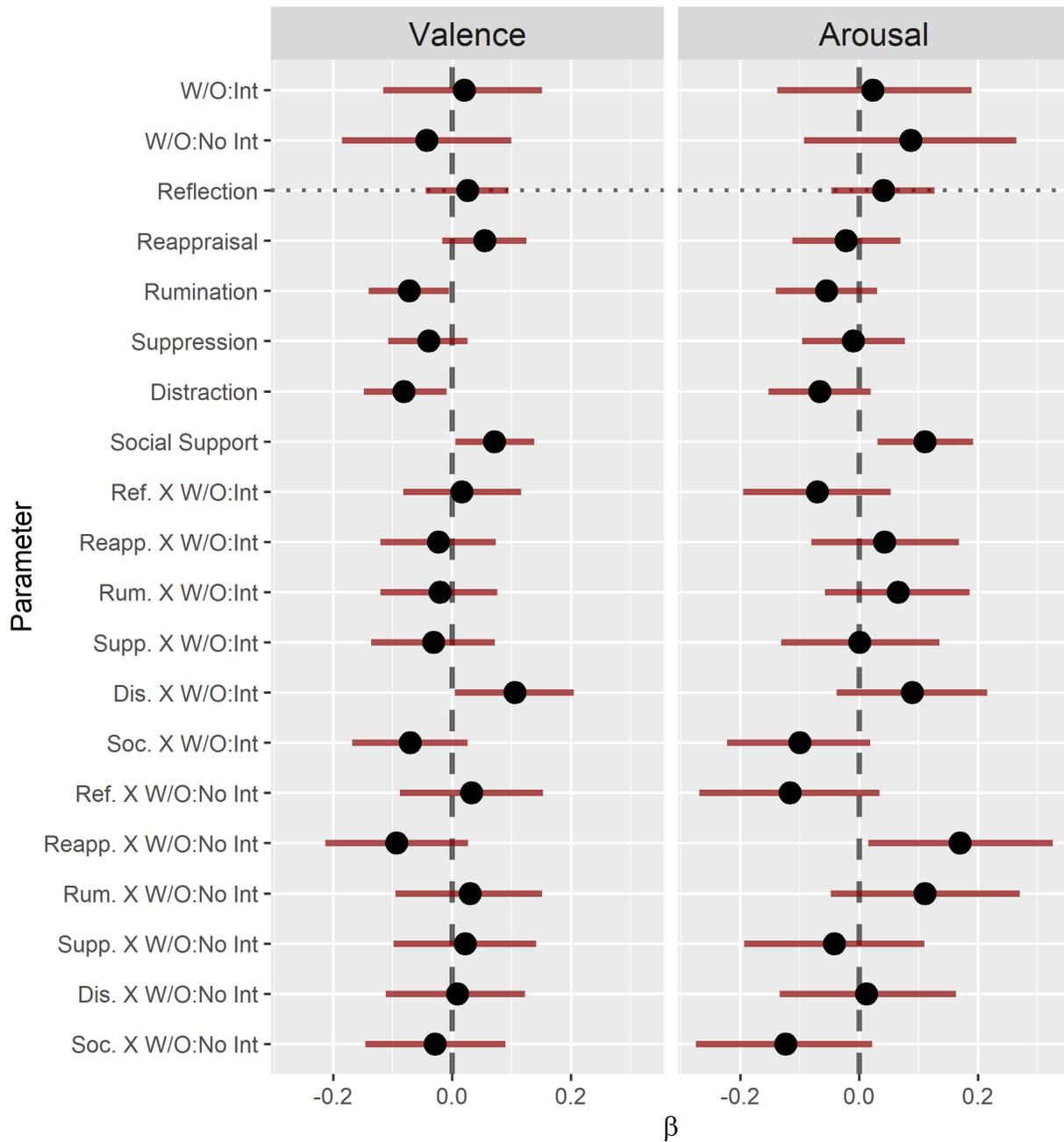
In addition to what we concluded from Model 1.1, we now conclude the following:

- Event polarity appears to interact with social context in predicting change in arousal. Specifically, being with others (either interacting or not) and experiencing a positive event is associated with stronger reduction in arousal.
- There is a small but reliable positive association between extraversion and Time 2 arousal, whereby those higher in extraversion tend to report higher Time 2 arousal.
- There are no Extraversion X Social Context or Preference for Solitude X Social Context interactions.

Model 1.3: Emotion Regulation Strategies

Finally, we consider the effects of using different emotion regulation strategies. We consider six strategies: *reflection*, *reappraisal*, *ruminatation*, *suppression*, *distraction*, and *social support*. We also consider their interactions with social context. Again, the model is mathematically similar to Models 1.1-2, but with more predictors. Posterior distributions for Model 1.3 coefficients are displayed in Figure 12. Here, for brevity, we only show parameters of interest (social context, strategies, and their interactions), but the model includes all the parameters from the previous models too.

Figure 12. Posterior distributions for model coefficients in Model 1.3.



Notes: Black dots represent posterior means, red lines represent the 95% credible interval (i.e., the range of values containing 95% of the mass of the posterior distribution). Coefficients from previous models (except social context) have been omitted from image for clarity.

There are quite a number of parameters in Model 1.3 because we include each of the six strategies and their interactions with social context. We note that most posterior distributions for the parameters overlap with zero and those that do not technically overlap are still quite close to zero. A few exceptions include social support on arousal, where we can see a fairly tight credible interval, suggesting that seeking social support is associated with greater arousal. A similar although slightly smaller effect is noticeable for valence, where social support seems to be associated with an increase in valence. Somewhat surprisingly, distraction appears to be weakly negatively associated with valence.

There is some indication that reappraisal interacts with social context, although this estimate is very uncertain. More specifically, this suggests a situation where using reappraisal while in the company of others and not interacting is positively associated with Time 2 arousal. However, given that the other Strategy X Context interactions are close to zero and uncertain, it is possible that this is a false positive. In the next section, we address this issue with model comparison.

Model 1.3 Summary

We draw the following conclusions from Model 1.3:

- We notice some main effects with emotion regulation strategies. Notable among these is social support, whereby those who engaged in more social support tended to report higher valence and arousal at Time 2.
- Reappraisal is weakly positively associated with Time 2 valence. In contrast, rumination, distraction, and (to a lesser extent) suppression appear to be negatively associated with Time 2 valence.

- Interactions among emotion regulation strategies and social context are scarce and highly uncertain.

Model Comparison

We perform model comparison using the procedure outlined in the earlier example. Table 7 shows the result of model comparison along the three criteria: WAIC, LOO, and weight. Models 1.1 and 1.2 performed much better than the more complex Model 1.3. So, we reject Model 1.3 on the grounds that it has comparatively less predictive accuracy.¹⁹ The difference between Model 1.1 and 1.2 is more subtle. Cross validation allocates somewhat more weight to the simpler 1.1, but not so much as to completely reject 1.2. The introduction of extraversion in Model 1.2 likely helps to predict valence and arousal even though it does not appear to be implicated in how these change from Time 1 to 2. Nevertheless, if we had to choose one model we would be justified in going with the simplest model, 1.1, which just includes Time 1 affect, social context, event polarity, and gender to predict Time 2 affect. From this we conclude that the covariates added from Models 1.2-3 (e.g., trait extraversion, preference for solitude, emotion regulation strategies) do not help to explain a sufficient amount of the variance in Time 2 affect.

¹⁹ Note that this does not necessarily mean that its coefficients are wrong, but that if we evaluate it as a whole, its complexity outweighs its predictive ability.

Table 7. Cross validation summary for Models 1.1-3.

Model #	WAIC (SE)	LOO	Weight
1.1	5138.9 (90.33)	-2569.7	0.60
1.2	5139.8 (90.62)	-2570.1	0.40
1.3	5151.9 (91.61)	-2576.3	0

Notes: Model 1.1 includes Time 1 affect, social context, and event polarity. Model 1.2 adds trait extraversion and preference for solitude and their interactions. Model 1.3 adds ER strategies and their interactions. WAIC = Watanabe-Akaike Information Criteria; LOO = Leave-One-Out Cross Validation; Weight = a rough estimate of how much “trust” we should put in each model given its scores on WAIC, LOO, and comparisons with other models (closer to 1 = preferred model).

Model 1.4: Does Extraversion Predict Social Context?

We previously focused on covariates that predict Time 2 affect. Both social context and extraversion appeared to be associated with affect, at least in a minor capacity. However, it is plausible that extraversion also predicts social context. A major component of extraversion is increased tendency to spend time with others (Lucas et al., 2008), so it makes sense that extraversion would predict both social context and affect. In other words, it is possible that social context may partially mediate the association between extraversion and affect. Short of performing a complete mediation analysis, which is avoided because it is ill-advised to conduct mediation analysis on cross-sectional data (Maxwell, Cole, & Mitchell, 2011), we will explore whether extraversion predicts different social contexts. This is technically a separate set of models from the previous set because we now shift our attention away from predicting Time 2 affect and toward predicting social context.

Because we are predicting social context, which is a nominal variable, the appropriate model will examine how the probability of being in a particular social context varies as a function of a set of covariates. This is called a *multinomial regression* model and it is essentially logistic regression but with more than two categorical outcomes. In multinomial regression we have an outcome variable composed of K unordered categories. The probability of the outcome taking on a particular k is defined as π_k and the sum of these probabilities over all k is equal to 1. We also must choose one k to act as a reference category, to which we will compare all other k . It made the most sense to assign Alone to be the reference category.²⁰ The model equation is as follows:

²⁰ The choice of reference category has no impact on the conclusions drawn from the model. It does, however, impact the values of the coefficients, meaning that we have to be careful about how we interpret these.

(5)

$$y_i \sim \text{Categorical Logit}(\text{softmax}(\mathbf{p}))$$

$$p_1 = \log\left(\frac{k_i = 1}{K}\right) = \beta_1 X_i$$

$$p_2 = \log\left(\frac{k_i = 2}{K}\right) = \beta_2 X_i$$

$$\vdots$$

$$p_{K-1} = \log\left(\frac{k_i = K - 1}{K}\right) = \beta_{K-1} X_i$$

$$\beta \sim \text{Normal}(0, 1)$$

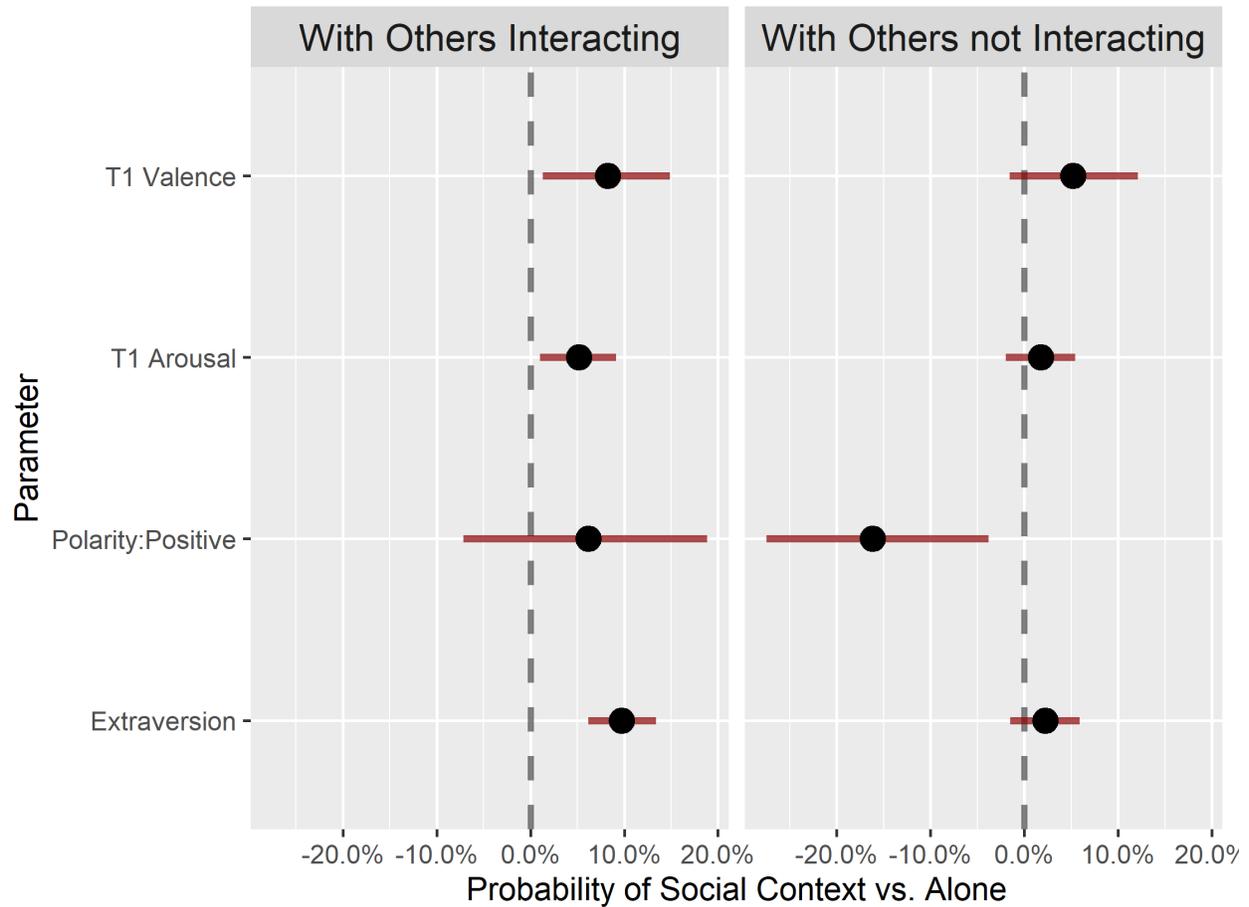
In Equation 5, y_i is social context and we use a *categorical logit* distribution parameterized by a vector of probabilities, \mathbf{p} , that are transformed to sum to 1 using the softmax function. For each of the $K - 1$ categorical outcomes, we use a logit link, $\log \frac{k_i}{K}$, so that it simply becomes a linear model with coefficients β and covariate matrix X . For β we use a default normal prior with mean 0 and standard deviation 1.

The covariates in this model include Time 1 affect, event polarity, and (importantly) extraversion. The reason for including Time 1 affect is because it is plausible that a person would choose a particular social context depending on their emotional state. Similarly, we might expect that depending on whether the event is positive or negative, people might choose different social contexts.

Figure 13 shows the model coefficients transformed from the log-odds scale to the probability scale. Each coefficient shows the change in probability compared to the reference category. For example, the bottommost coefficient on the left panel tells us that extraversion is associated with an average ten percent increase the probability of interacting with someone compared to being alone. We see as well that Time 1 valence is positively associated with a

greater likelihood of being with others and interacting. There is also some evidence that arousal is positively associated with the likelihood of interacting with others, although this effect is considerably smaller than that for valence. Although we controlled for Time 1 affect in the models predicting Time 2 affect from social context, it is important to acknowledge that affect is likely both a cause and consequence of social context. Finally, one is more likely (~20 percent) to be in the context of others but *not* interacting instead of alone when experiencing a negative event. This suggests that extraversion may confound the relation between social context and change in affect.

Figure 13. Mean posterior distribution and 95% credibility interval for model predicting probability of social context as a function of Time 1 affect, event polarity, and extraversion.



Notes: Original log-odds converted to probability for interpretability. Probabilities are centered at 0 such that the value corresponds to how more or less likely one is to be in one of the social contexts compared to alone.

Study 1 Discussion

The goal of Study 1 was to gain an initial understanding about the relation between social context and change in emotion following an emotional event. A series of models evaluated the extent to which social context, event polarity, trait extraversion and preference for solitude, and emotion regulation strategies predicted change in valence and arousal (i.e., Time 2 affect controlling for Time 1 affect). All three models showed marginal support for the role of social context (alone vs. with others) in affecting Time 2 valence *and* arousal. Specifically, results indicated that those who were alone reported a stronger decrease in arousal compared to those who were with others (interacting or not). Moreover, those who were with others and interacting reported a mild increase in valence compared to those who were alone or with others but not interacting. Model comparison showed that the two simpler models (i.e., the ones without emotion regulation strategies) are likely to have better predictive utility and therefore we limit our interpretation to these models.

Hypothesis 1: Is There Evidence of a Deactivation Effect?

Solitude is generally reported as a context where negative affect is more prevalent (e.g., Zelenski et al., 2013). However, previous research has suggested that solitude may be helpful in reducing high arousal emotions (e.g., stress, excitedness). This is referred to as the deactivation effect of solitude and is borne out in experimental research (Nguyen et al., 2018), but had yet to be tested in a more naturalistic context. Accordingly, the first hypothesis was that arousal would decrease more strongly when someone was alone compared to when they were with others. Results from Study 1 were generally consistent with a deactivation effect of solitude, but only in the context of negative events and not positive events. Focusing on negative events, people tended to report a greater reduction in arousal following a negative event if they were alone

compared to with others. Interestingly, the mean posterior distribution of the standardized estimate is strikingly similar to the maximum likelihood estimate obtained in previous research: -0.33 in the current study and -0.30 in Nguyen et al. Overall, this result is consistent with the idea that solitude may help alleviate arousal in the context of negative events. Indeed, researchers have theorized that solitude can “take the edge off” of intense negative emotions (Coplan, Hipson, et al., 2019; Larson, 1995).

However, we did not find evidence of deactivation in the context of positive events. In this context, being alone appears to be associated with a stronger *increase* in arousal following a positive event. Specifically, 46 percent of the time we would expect arousal to decrease when alone, which contrasts with the greater than chance expectation for the other social conditions. Thus, there is an asymmetry between positive and negative events; and although we focus predominately on negative events because they are more pertinent to the task of emotion regulation and coping, this asymmetry casts further doubt on whether the deactivation effect is valid in different contexts.

It is important to distinguish between the methods used in the current study and those Nguyen et al. (2018) used, as this distinction may help to explain the somewhat divergent findings. The main difference is that we asked participants to reflect on emotional events and how their emotions changed following the event, whereas Nguyen et al. had participants report change in baseline affect. Actual positive events (e.g., getting a desired job offer, receiving encouragement from a friend, etc.) involve more dramatic change in affect compared to the minor fluctuations in baseline affect. Perhaps the strong tendency for affect to return to baseline following a positive event overwhelms any potential minor differences that result from social context (Kappas, 2011; Porges et al., 1994).

It is also possible that the different approach to measuring valence and arousal may have attributed to the divergent results. Nguyen et al. (2018) used emotion labels (e.g., calm, tense, sleepy) to measure valence-arousal combinations, whereas the current study asked participants about arousal and valence directly, similar to the approach used by Kuppens, Oravecz, et al. (2010) and Russell et al., (1980). In the former approach, people may find it easier to reflect on abstract concepts like arousal if they can tie it to concrete emotion states. There is also evidence to suggest that people have difficulty thinking of valence and arousal in isolation (Kron et al., 2013; Kron, 2019).

The results from the current study also cast some doubt on the practical magnitude of the deactivation effect in the real world. On the one hand, there is solid probability of a non-zero difference between being alone and being with others (either interacting or not). On the other hand, to say that solitude is associated with reduced arousal would be misleading. Posterior predictive simulation found that we would expect only 55 percent of people who are alone to experience reduced arousal during a negative event. Therefore, although this probability is *relatively* larger than the probability of arousal decreasing in other social contexts, it has little practical value if we want to predict whether being alone is associated with a decrease in arousal. This also does not speak to the magnitude of the decrease itself, which is on average very close to zero.

Hypothesis 2: Change in Valence

The second hypothesis was that people would report higher valence when they were with others and interacting, but that there would no difference in the other two conditions: alone and with others not interacting. The current results are partially consistent with this hypothesis. On the one hand, following positive events, interacting with others was associated with a weaker

decrease in valence. Specifically, we would expect that valence would decrease approximately 54 percent of the time when interacting with others compared to 61 percent and 63 percent of the time in the alone and with others not interacting contexts. On the other hand, the same pattern is not true for negative events, where the alone and interacting contexts have the same expected reduction in valence.

Previous studies have found that valence is amplified while in the context of others (Boothby et al., 2014). Our findings add to this by suggesting that the regular tendency of valence to *decrease* following a positive event may be mitigated by spending the time interacting with others. This finding is relatively novel because it pertains to change in emotion following an event, whereas most previous research has focused on affect at a single time point. These previous studies have tended to find that being with others is conducive to positive emotions (Kahneman et al., 2004; Reis et al., 2017), but the current findings go further in suggesting that being with others helps *sustain* valence. Nevertheless, the current evidence is still not robust enough to suggest a causal link between interacting with others and valence.

It is somewhat surprising that there was no discernible difference among the social context conditions in change in valence following a negative event. This contrasts with previous research suggesting that negative stimuli are more bearable when a friend or even a stranger is nearby (Coan et al., 2006; Schnall et al., 2008). Indeed, it is even more surprising that social support as an emotion regulation strategy did not reliably increase valence, which goes against extensive research on the importance of social support (Marroquin, 2011; Zaki & Williams, 2013). One explanation for the current findings is that the type of relationship that the person has with their social interaction partner matters in predicting change in valence. The current study did not attempt to distinguish between interacting with a friend, stranger, co-worker, nemesis,

etc. Although some previous evidence suggests that interacting with a stranger still produces increases in valence (Coan et al., 2006; Epley & Schroeder, 2014; Zelenski et al., 2013), in many cases the effect is subdued (Coan et al., 2006). Moreover, it is possible that the social interaction partner is responsible for causing or instigating the negative event – something that the current study did not attempt to identify.

Hypothesis 3: Does Extraversion Moderate Deactivation?

A third hypothesis was that the deactivation effect of solitude would be weaker among those higher in extraversion. The current study found no evidence to support this hypothesis. Despite the popular appeal of the claim that solitude is especially calming restorative for introverts (e.g., Cain, 2012), there have been few attempts to test it empirically. Some studies have indirectly offered support for this claim. For instance, Leung (2015) found that those who desired solitude and spent time alone with their tablet or phone reported reduced stress.

It is surprising that previous studies and the current study have failed to find that introversion moderates deactivation because one of the hallmarks of introversion is a lower threshold for arousal, which is purported to be the main factor contributing to introvert's tendency to spend more time alone (Geen, 1984). In a similar vein, those higher in introversion tend to prefer being a lower arousal states (Geen, 1997; Hills & Argyle, 2001; Rusting & Larsen, 1995; Smillie et al., 2012). Thus, a more plausible explanation perhaps is that introverts seek solitude *because it is deactivating* but are no more likely to experience deactivation than extraverts. Introverts may like the fact that solitude reduces arousal, but this does not mean that they experience a stronger deactivation.

Hypothesis 4: Does Preference for Solitude Moderate Change in Valence?

A fourth hypothesis is that valence would increase (or decrease less) in the context of solitude only among those who are higher in preference for solitude. The idea here is that people who enjoy being alone for *intrinsic* reasons will find time alone more pleasant. However, the current study found no convincing evidence of this hypothesis. We have to consider again that people in the current study were reflecting on affect following an emotional event, whereas most discussions about preference for solitude are framed in the context of baseline affect (e.g., Kahneman et al., 2004; Reis et al., 2017). Thus, it is possible that the potential interaction between preference for solitude and time alone would be different under more normal circumstances.

Although it seems counterintuitive that people who report preferring time alone would not experience this time alone as more pleasant, there are a number of studies suggesting that the relation between preference for solitude and subsequent enjoyment of time alone is more complicated. For example, correlational studies tend to find that preference for solitude correlates with affect in much the same way that shyness and social anxiety do (i.e., positively associated with low self-esteem, negative affect, anxiety, and depression; Burger, 1995; Maes et al., 2016; Teppers et al., 2014; Waskowic & Cramer, 1999). These findings may be at least partly due to issues in operationalizing and measuring preference for solitude. For instance, some measures of preference for solitude collapse multiple diverse reasons for preferring solitude (e.g., for reflection, getting away from others, doing meaningful activities, etc.) into a single metric. Measures of preference for solitude that include items pertaining to escaping others or avoiding others are likely tapping into constructs like social anxiety and social avoidance, which would

explain why preference for solitude is sometimes found to correlate with these other measures (Wang et al., 2013).

Experience sampling studies tend to find more positive associations between momentary desire for solitude and affect. For instance, Lay et al. (2018) reported that preference for solitude (as measured by average desire for solitude over a series of experience sampling prompts) increased the likelihood of experiencing solitude as calming and enjoyable. Coplan, Hipson, et al. (2019) have attempted to explain these paradoxical findings by suggesting that preference for solitude is problematic only when one's need for solitude is not being met. They further speculate that solitude is only satisfying under certain conditions, such as when the person is engaged in an activity that is personally fulfilling (Coplan, Hipson, et al., 2021; Nguyen et al., 2019). Thus, further research examining the quality of time alone is needed to better understand how preference for solitude and time alone interact to predict affect.

Hypothesis 5: Emotion Regulation Strategies and Change in Affect

The fifth hypothesis focused exclusively on emotion regulation strategies and their relation to change in valence. We tentatively hypothesized that distraction and reappraisal would be positively associated with an increase (or lower decrease) in valence following both positive and negative events, whereas the opposite would hold for rumination and suppression. Again, contrary to hypotheses, emotion regulation strategies were of minimal relation with change in affect. Although some appeared to have a marginal association with Time 2 valence, the model that included these strategies performed poorly compared to the previous models. It is likely that the single time point assessment of strategies was insufficient to unveil the effects of different strategies. Further, previous studies suggest that strategies are highly individualized, which means a strategy that is effective for one person may be ineffective for another person (Bonanno

& Burton, 2013). Multilevel modelling with repeated measures designs is needed to parse the individual strategy effects from the fixed strategy effects. This is the focus of Study 3, so we save a more detailed discussion of emotion regulation strategies for that section.

Hypothesis 6: Gender Differences in Change in Affect

We explored gender main effects in change in arousal and valence. The sixth hypothesis tentatively postulated that there would be no gender differences. We find that there is no difference between men and women in change in affect – the posterior distribution is strongly centered at zero. For gender non-binary and missing/NA, there is too much posterior uncertainty to conclude or reject differences.

We do not focus extensively on gender differences in this dissertation. One reason for this is that there is considerable inconsistency in reported gender differences in the extant emotion and emotion regulation literature (McRae et al., 2008; Nolen-Hoeksema, 2012; Nolen-Hoeksema & Aldao, 2011; Zimmermann & Iwanski, 2014), suggesting that there is much more variation *within* gender than there is between gender. Where research in gender differences is conclusive has to do with reporting of negative emotion and mood and not in how these change over time. For instance, there is consistent research suggesting that women report more negative mood than men and are more likely to report and seek treatment for depression and anxiety (Nolen-Hoeksema, 2012). However, there is reason to suspect that gender differences in mood may be decreasing over time (see Stevenson & Wolfers, 2008). All of this is to say that gender, on its own, is likely not predictive of *change* in emotion.

Hypothesis 7: Extraversion and Social Context – A Third Variable Problem

The final hypothesis of Study 1 was that extraversion would predict which social context a person would seek out following an emotional event. Specifically, those higher in extraversion

were expected to be in an interacting context instead of alone or just in the vicinity of others. The current findings support this hypothesis – a one standard-unit increase in extraversion was associated with a 10 percent increase in the likelihood of interacting with others instead of being alone, but no difference in being with others and not interacting. This is of course consistent with a large body of research indicating that extraverts spend more time around others (see Zelenski et al., 2014).

This finding, however, adds another layer of uncertainty to the proposed deactivation effect. The reason is that extraversion is associated with both changes in affect – extraverts tend to experience higher positive arousal and tend to prefer higher arousal states (Hemenover, 2003) – and extraversion is associated with increased probability of being with others, as evidenced by the current study and previous research. Thus, it may be that extraversion is driving the apparent deactivation effect, whereby extraverts choose a more “social” context and subsequently experience higher arousal because they inherently prefer high arousal states. In the absence of experimental research, this remains speculative, but we should be careful to not interpret the current findings with a causal framework.

Study 1 Limitations and Conclusion

The main goal of Study 1 was to examine the deactivation effect of solitude. Taken together, the evidence from Study 1 points to marginal support for a deactivation effect but only in the context of negative events. Although these findings are consistent with previous research (Nguyen et al., 2018), there are some reasons to remain skeptical. Here, we address limitations of the current study – some of which are improved upon in subsequent studies.

First, trying to pin down complex time-dependent dynamics using a single-time point is a near hopeless task and one that is sure to bear results with questionable validity. From a

measurement perspective we should be extremely skeptical about whether people can accurately recall what they were doing and how they felt in the past 24 hours. A plethora of studies cautions us against interpreting these reports too strongly because of recall bias (e.g., Ebner-Priemer et al., 2006). Daily diary and experience sampling approaches offer an ideal alternative for measuring momentary affect as the reduced time interval between the event and the self-report reduce the likelihood of recall bias.

Another issue is that we intentionally gave participants a broad definition of solitude (any situation in which they were ‘alone’). There is no universally accepted definition of solitude in the literature, and it is likely that participants would also vary in their understanding of the term ‘alone’. As we have highlighted, technology further complicates the definition of solitude (Kushlev et al., 2016). For example, a person could be physically alone but interacting with others, or with others but *feel* alone. We attempted to deal with some of these nuances by allowing participants to choose between *interacting with others* and *with others but not interacting*. However, future research is needed on how solitude is perceived or experienced differently as a function of technology and communication.

One possibility that remains to be explored is that deactivation depends on what people are doing while they are alone, such that the effect may only occur under specific types of solitary conditions. Nguyen et al. (2018) addressed this to some extent by comparing a condition where people were alone but instructed to do an activity (reading) against a condition where people could choose what they wanted to do, and found that regardless of whether participants were engaged in an activity, solitude remained deactivating. They also explored whether instructing people to think positive (vs. neutral) thoughts impacted the deactivation effect and found that positive thinking indeed increased the strength of the effect. By contrast, we had no

way of controlling how participants spent their time alone and is conceivable that people may have been alone doing any number of things not conducive to deactivation. For instance, people could have been driving alone in rush hour traffic²¹ or doing something dreadful like filing their taxes. Study 2 attempts to address some of these questions, but for now we can imagine that there are many obvious cases in which a person is alone but, by nature of what they are doing, their solitude is by no means deactivating.

Study 2: Solitude, Solitary Activities, and Personality on Affect

Study 1 provided some initial (albeit weak) evidence that social context is associated with change in arousal, however, due to the cross-sectional nature of the data, this evidence was far from conclusive. Study 2 was designed to establish the causal role of social context in emotion dynamics. This plan originally included a baseline assessment of personality traits, emotion regulation capabilities, and recent patterns of time alone, followed by a two-week experience sampling paradigm.

In March of 2020, while the baseline phase of the study was well underway and the experience sampling phase was about to begin, the World Health Organization declared the ongoing COVID-19 virus to be a global pandemic and the experience sampling phase of the study was indefinitely shuttered. Baseline data collection continued but with heavily reduced participation rate. Despite the limitations of cross-sectional data, the models for Study 2 use only this baseline data.

The new goal for Study 2 was then to evaluate the extent to which time alone and activities performed while alone were associated with high arousal negative affect and high

²¹ It is interesting to think about whether driving alone in traffic constitutes solitude. Although the person is within the confines of their vehicle, there is minimal privacy and they are expected to negotiate with other drivers on the road. There is occasionally social interaction too – it could be signalling thank-you to another driver, giving the middle finger, or honking the horn.

arousal positive affect. There are an infinite number of ways to categorize the way that people spend their time alone. Although this study includes a wide variety of activities, there are five types of activities that are of theoretical interest. First were *intrinsically motivated* activities, which is a broad category reflecting activities for pleasure or fulfillment, and includes things like hobbies, reading for pleasure, and listening to music. Next was *screen time*, which includes both “social” and “non-social” forms of screen-based media, such as social media, watching TV, browsing internet, and playing video games. Next was *outdoors*, which is of interest because of previously mentioned research expounding the benefits of being alone in nature (Kaplan et al., 1995). *Meditation* (which includes spiritual and non-spiritual types of meditation), is of interest as many have suggested that solitude affords the opportunity to meditate and reflect (Larson, 1995). Despite these claims, there is good reason to be skeptical of meaningful associations between meditation and affect (e.g., Goyal et al., 2014). Finally, *worry* (which includes negative thinking and ruminating) is the only completely “cognitive” activity that we focus on this dissertation. Worrying is of interest because there is evidence that when people are alone their minds often wander toward negative thoughts (Wilson et al., 2019).

Study 2 Hypotheses

Because of the change in plan brought on by COVID-19, the original hypotheses were modified. As a result, these hypotheses are somewhat more speculative, and the current data may be too limited to fully address them.

- 1) Those who spend more time alone will tend to report lower high arousal negative affect and lower high arousal positive affect. This is in line with the idea of a deactivation effect, although here we are limited to testing it at the “trait” level because we only have data on average time spent alone.

- 2) Extraversion will be positively associated with high arousal positive affect and negatively associated with high arousal negative affect. This hypothesis comes from the well-documented link between extraversion and happiness (Tellegen, 1985; Wilt et al., 2012; Zelenski et al., 2021). In contrast, preference for solitude is not expected to be associated with affect.
- 3) Time alone will interact with preference for solitude and extraversion to predict positive and negative affect. Specifically, those who prefer solitude and report spending more time alone will report higher positive and lower negative affect. The pattern will be similar with respect to extraversion. Although Study 1 failed to find an interaction between preference for solitude and time alone in the prediction of *change* in affect, we still expect – at least tentatively – that the interaction will hold in the prediction of trait affect.
- 4) Engaging in different activities while alone will be differentially associated with the link between time alone and affect. Specifically, it is hypothesized that activities that are likely to be intrinsically motivated (e.g., reading for pleasure, hobbies, listening to music, being outdoors) (Kleiber et al., 1986) will be negatively associated with negative affect and positively associated with positive affect. In contrast, increased tendency to worry while alone is expected to have the reverse pattern of associations. Other activities are not expected to be associated with affect. Previous studies have found mixed or null associations between screen time and well-being (Orben et al., 2019) and there is no reason to suspect any direct link between spending more time outdoors or meditating and affect. These hypotheses are only tentative because there is a lack of research specifically examining links between solitary activities and well-being – only a handful of studies

have explored this and the results only hint at a potential link between intrinsically motivated activities and well-being (Coplan, Hipson, et al., 2021; Hipson, Coplan, et al., 2021).

- 5) We also hypothesize that some solitary activities may interact with time alone to predict affect. Emerging evidence suggests that doing intrinsically motivated activities (i.e., hobbies) while alone is rewarding (Coplan, Hipson, et al., 2021). Thus, among those who tend to engage in hobbies while alone, time alone may be more positively associated with positive affect.

Participants and Procedure

Data for Study 2 were collected during the late Fall of 2019 and early Winter of 2020. Participants were $N = 215$ first- and second-year psychology students (159 women, 54 men, 1 non-binary, and 1 prefer to not answer) at Carleton University ranging from 17 to 53 years of age ($M = 20.39$, $SD = 4.22$).²² The majority of participants were White (56.30%), followed by Asian (16.30%), African-Canadian (10.70%), Other (9.77%), Hispanic (4.65%), and Aboriginal (0.93%).

All procedures were approved by CUREB-B. The online survey was designed to take approximately 20 minutes to complete. All participants first received demographic questionnaires (e.g., sex, age, and ethnicity) followed by time alone and activities. The remaining questionnaires were received in randomized order.

²² Participation rate was substantively lower for Study 2 compared to Study 1. Likely reasons for this include the delay in study launch, the instruction that it was a two-part study with a laboratory component (despite the 2nd part being optional), and the onset of the COVID-19 pandemic in March of 2020.

Measures

Positive and negative affect.

The measure of affect for the baseline data was the *Positive and Negative Affect Schedule* (PANAS; Watson & Tellegen, 1985). The PANAS includes a 10-item subscale for *positive affect* ($\alpha = 0.88$ in the current study) and a 10-item subscale for *negative affect* ($\alpha = 0.85$). This measure has previously been shown to be reliable and valid across diverse samples (e.g., clinical, normative) (Crawford & Henry, 2004).

The PANAS was originally to serve only as a baseline while a more rigorous valence-arousal account of affect was to be included in the ill-fated experience sampling phase. The main disadvantage of the PANAS for the current purposes is that it only includes items pertaining to *high arousal* positive and negative affect (e.g., agitated, excited, alert). Nevertheless, given that arousal is continuous, we can still draw tentative inferences about relations with low arousal if we take the lower end of the scale to represent low arousal.

Time alone.

Time spent alone was measured as the average of two items. The first assessed the number of times the participant was alone (defined as “by yourself or doing something by yourself – not including sleeping”) for at least fifteen minutes (1 = not at all during the last week, 6 = more than 4 times each day last week). The second assessed the total number of hours spent alone during the previous week (1 = less than 7 hours/less than 1 hour per day, 6 = more than 35 hours/more than 5 hours per day) (in this study, $\alpha = 0.83$). This measure has previously been found to have good construct validity (i.e., positively associated with preference for solitude; Coplan, Hipson, et al., 2019).

Extraversion.

As in Study 1, extraversion was measured using the extraversion subscale (in this study, $\alpha = 0.87$, in the current study) from the Big Five Inventory (John & Srivastava, 1999). (see Study 1 for discussion of reliability and validity).

Solitary activities.

Participants were asked to rank the following 10 categories of activities in order of how often they did the activity while alone in the last week: 1: *Screen time (e.g., TV, phone, computer)*, 2: *Hobbies (e.g., art, musical instruments, dance, colouring)*, 3: *Reading for pleasure*, 4: *Listening to music*, 5: *School work*, 6: *Physical exercise*, 7: *Outdoors*, 8: *Meditating or praying*, 9: *Worrying about things*, 10: *Chores or housework*. These categories were chosen based on our previous work where we developed a coding scheme of solitary activities based on open-ended responses (Hipson, Coplan, et al., 2021). This previous coding scheme was also inspired by earlier theoretical work (see Larson, 1995; Long et al., 2003). In the current study, all ten activity categories are included as covariates, although it is noted that only a select few are of theoretical interest. These include: screen time, hobbies, reading, listening to music, outdoors, meditating, and worry.

Transforming ranked activity variables.

Although the ranking approach had the advantage of allowing for comparisons among activities, it posed some analytical challenges. Namely, it seemed unlikely that the ordinal rank decreased linearly. In other words, there would be meaningful differences between Rank 1 and 2 but presumably less so between Rank 5 and 6. Thus, we transform these rankings to increase the likelihood that the ordering would be linear, while still preserving the meaningful order. A further consideration here was that these variables were not independent – each rank depended

completely on how the other variables were ranked. However, we wanted to be able to treat these variables as if they were independent. To summarize, we wanted the measure to reflect the extent to which a participant performed that particular activity while alone.

The following describes an information theoretic approach to transform the ranked variables. It assumes that ranks at the beginning and end would have less *entropy* than ranks in the middle. In information theory, *entropy* is a measure of uncertainty in a set of probabilistic outcomes (MacKay, 2003; Shannon, 1948). Entropy is computed as follows:

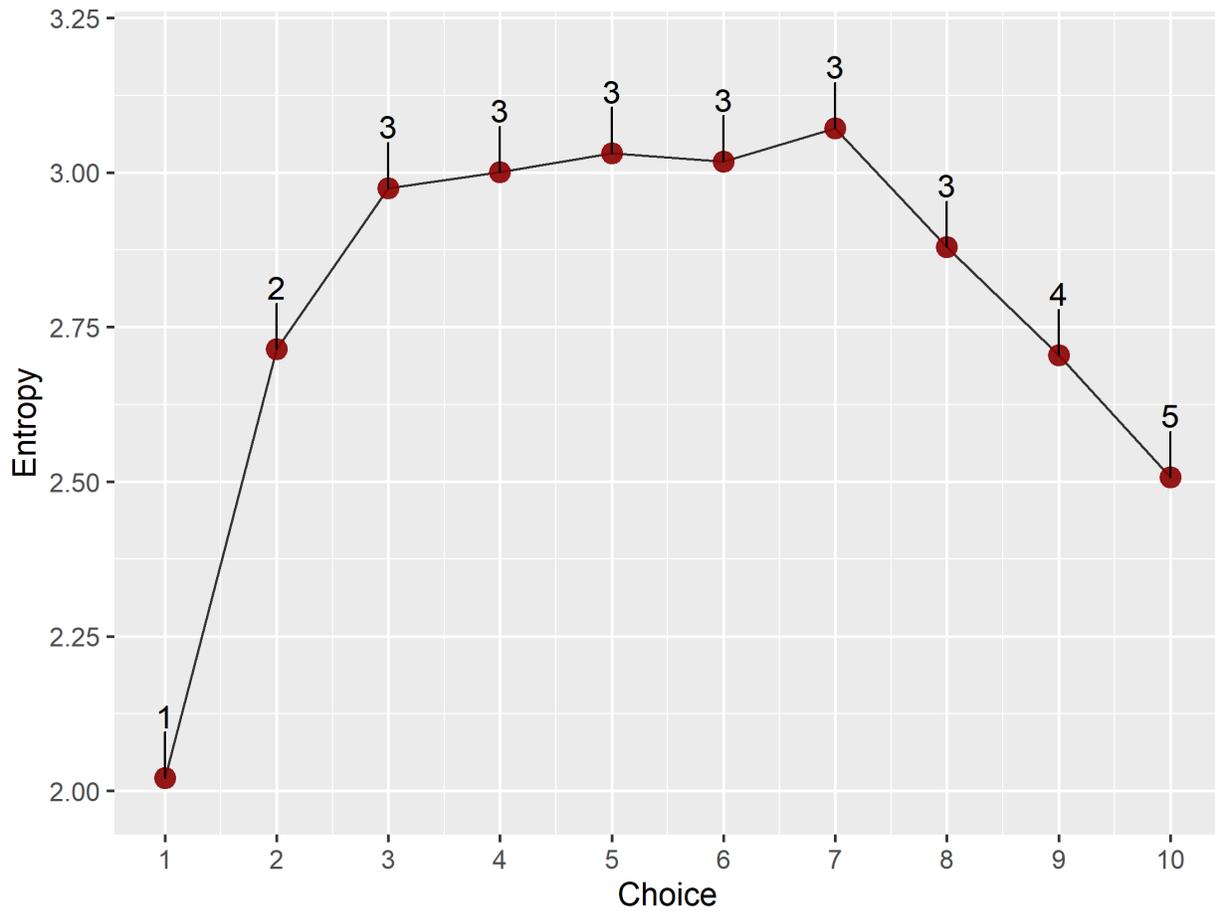
(6)

$$H(X) = \sum_i p_i \log_2 \frac{1}{p_i}$$

X is used to denote a set of probabilistic outcomes (e.g., the probabilities of choosing each activity as Rank 1), p_i is the probability of outcome i . This gives us a measure of the amount of uncertainty in set of outcomes.

The goal was to use entropy for each rank to determine which ranks could be grouped together, thus reducing the rank from 10 to something more approachable and increasing the linearity of the scale. For each of the ranks from 1 to 10, we calculated the relative proportions of activities in that rank. We then computed the entropy for each rank. Figure 14 shows the entropy for each of the 10 rankings. We see that entropy is relatively low for Ranks 1, 2, 9, and 10, but high among Ranks 3 to 8. In other words, we learn more information from looking at the first two and last two ranks, but we learn relatively little from the intermediate ranks. We used this as a basis to combine Ranks 3 to 8 into the same score, resulting in a scale from 1 to 5 for each of the activities. These variables could then be entered normally as predictors in the subsequent regression models.

Figure 14. Entropy as a function of solitude activity choice.



Notes: Low entropy implies more order whereas high entropy implies more disorder. Ranks in the middle of the scale are more disordered, suggesting that participants are less able to distinguish meaningfully amount these rankings. Numbers above the points represent the transformed value for each ranking based on its entropy.

Data Preparation and Cleaning

Study 2 involved the same procedures described in Study 1 for handling outliers and missing data. Of note, there were no multivariate outliers (according to Mahalanobis Distance) nor was there pervasive string responding. In fact, participants in this study all took reasonable time to complete the survey.²³ However, missing data was somewhat more common in this study with ~5% missing on solitary activities and ~6% missing on trait variables. As in Study 1, missing data was handled using full Bayesian imputation.

Study 2 Results

Descriptive Statistics

Descriptive statistics for continuous variables are presented in Table 8. This table shows the raw ranks for each of the solitary activity categories *prior* to the transformation. *Screen Time* is the most frequent solitary activity, followed in descending order by *School Work*, *Listening to Music*, *Worrying*, *Hobbies*, *Chores*, *Exercise*, *Reading*, *Outdoors*, and *Meditation*.

²³ It is speculated that because Study 2 was advertised as a two-part study with an in-person component, participants who tend to lazily complete surveys were less likely to enrol to begin with.

Table 8. Descriptive statistics for continuous variables in Study 2.

	Mean	SD	Min	Max
Time Alone	4.05	1.58	1.00	6.00
Screen Time	1.96	1.61	1.00	10.00
Hobbies	5.54	2.34	1.00	10.00
Reading	7.08	2.55	1.00	11.00
Listening to Music	3.81	1.91	1.00	10.00
School Work	3.61	2.04	1.00	10.00
Exercise	6.26	2.45	1.00	11.00
Outdoors	7.16	2.09	1.00	11.00
Meditation	8.37	1.99	1.00	11.00
Worry	5.40	2.86	1.00	11.00
Chores	6.26	2.53	1.00	10.00
Negative Affect	2.42	0.75	1.00	4.80
Positive Affect	3.09	0.74	1.10	4.70
Pref. Solitude	4.60	1.09	1.33	6.89
Extraversion	2.67	0.85	0.62	4.50

Notes: Activities (Screen Time – Chores) are presented in their raw ranking, where 1 = highest rank.

Pairwise correlations are presented in Table 9, along with p -values for descriptive purposes. Of note, extraversion is negatively correlated with preference for solitude ($r = -0.23$; Study 1: $r = -0.35$). Time alone is negatively correlated with preference for solitude ($r = -0.16$) and Music Listening ($r = -0.15$). In contrast, time alone is positively correlated with Outdoors ($r = 0.15$) and Chores ($r = 0.19$).

Table 9. Pairwise correlation coefficients for continuous variables in Study 2

	Time Alone	Screen	Hobbies	Reading	Music	Sch. Work	Exercise	Outdoors	Meditation	Worry	Chores	Negative	Positive	Pref. Sol
Time Alone	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Screen Time	-0.11	-	-	-	-	-	-	-	-	-	-	-	-	-
Hobbies	-0.08	-0.07	-	-	-	-	-	-	-	-	-	-	-	-
Reading	-0.03	-0.09	0.12	-	-	-	-	-	-	-	-	-	-	-
Listening to Music	-0.15*	0.03	0.09	-0.15*	-	-	-	-	-	-	-	-	-	-
School Work	0.03	-0.22**	-0.1	-0.06	-0.28***	-	-	-	-	-	-	-	-	-
Exercise	0.04	-0.24***	-0.02	-0.19**	-0.14*	0.09	-	-	-	-	-	-	-	-
Outdoors	0.15*	-0.05	-0.1	-0.27***	-0.12	-0.03	0.27***	-	-	-	-	-	-	-
Meditation	0.02	-0.11	-0.09	0	-0.15*	-0.08	-0.13	-0.16*	-	-	-	-	-	-
Worry	-0.03	0.13	-0.31***	-0.09	0	-0.18**	-0.4***	-0.32***	-0.01	-	-	-	-	-
Chores	0.19**	-0.02	-0.36***	-0.38***	-0.1	-0.01	-0.17*	0.01	-0.15*	0.04	-	-	-	-
Negative Affect	0.06	-0.03	0.17*	0.03	0.07	0.05	0.22**	0.12	-0.17*	-0.49***	0.06	-	-	-
Positive Affect	-0.07	0.2**	-0.08	0.13	-0.01	-0.12	-0.36***	-0.27***	0.02	0.49***	-0.06	-0.2**	-	-
Pref. Solitude	0.12	0.15*	-0.06	-0.08	-0.07	-0.15*	-0.02	0.14*	-0.04	0.02	0.1	-0.06	0.04	-
Extraversion	-0.16*	0.08	-0.05	0.1	0.07	-0.01	-0.23***	-0.22**	0.03	0.28***	-0.08	-0.21**	0.52***	-0.23***

Notes: p -values are presented for descriptive purposes. *** < 0.001, ** < 0.01, * < 0.05. Activity variables are not transformed.

Study 2 Models Overview

There are three models in Study 2, each predicting positive and negative affect, and with each model increasing in complexity. We use SUR to jointly predict positive and negative affect from a series of covariates. Model 2.1 includes “trait” variables as covariates, Model 2.2 added solitary activities, and Model 2.3 adds relevant interaction terms as predictors.

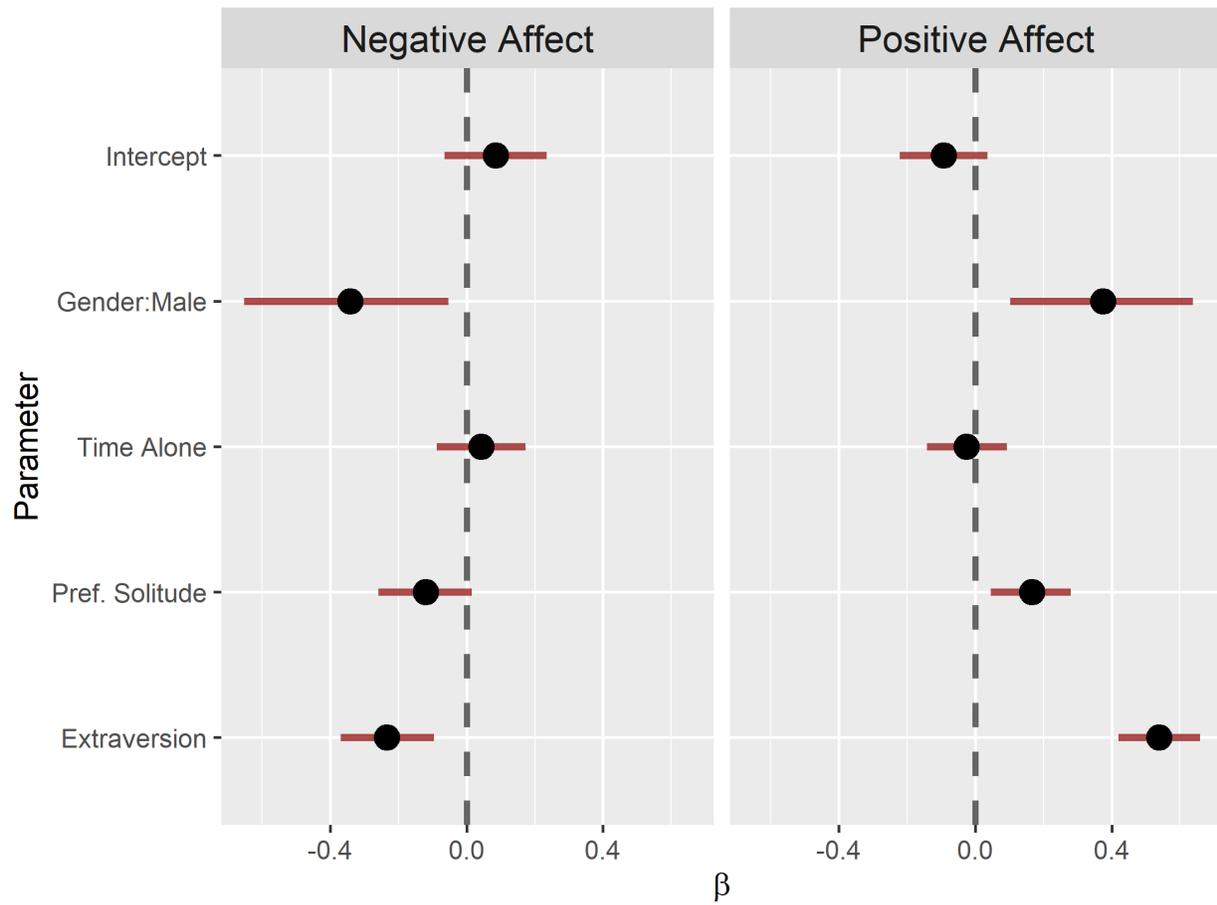
Model 2.1: Time alone, activities, and high arousal affect

Model 2.1 included negative and positive affect as outcomes predicted by the following covariates: *gender*, *time alone*, *preference for solitude*, and *extraversion*. Note that this first model did not include solitary activities so as to establish baseline performance prior to including these. These models used an identical structure to those in Study 1 as specified in Equation 4.

Posterior means and intervals for Model 2.1 coefficients are presented in Figure 15. We see fairly strong evidence for an association between extraversion and affect. Specifically, extraversion is negatively associated with negative affect and positively associated with positive affect. Indeed, the positive association with positive affect appears particularly robust, where a 1 standard unit increase in extraversion corresponds quite reliably to a 0.5 standard unit increase in positive affect. There is also some indication of a positive association between preference for solitude and positive affect. This is partially mirrored in the prediction of negative affect, although the uncertainty in this case is more noticeable.

There also appears to be an effect of gender, whereby being male is negatively associated with negative affect and positively associated with positive affect. Nevertheless, the posterior distribution for gender is quite uncertain, which is most likely attributed to the low proportion of males in the sample. Finally, there does not appear to be an association with time alone for neither positive nor negative affect.

Figure 15. Posterior distributions for coefficients in Model 2.1.

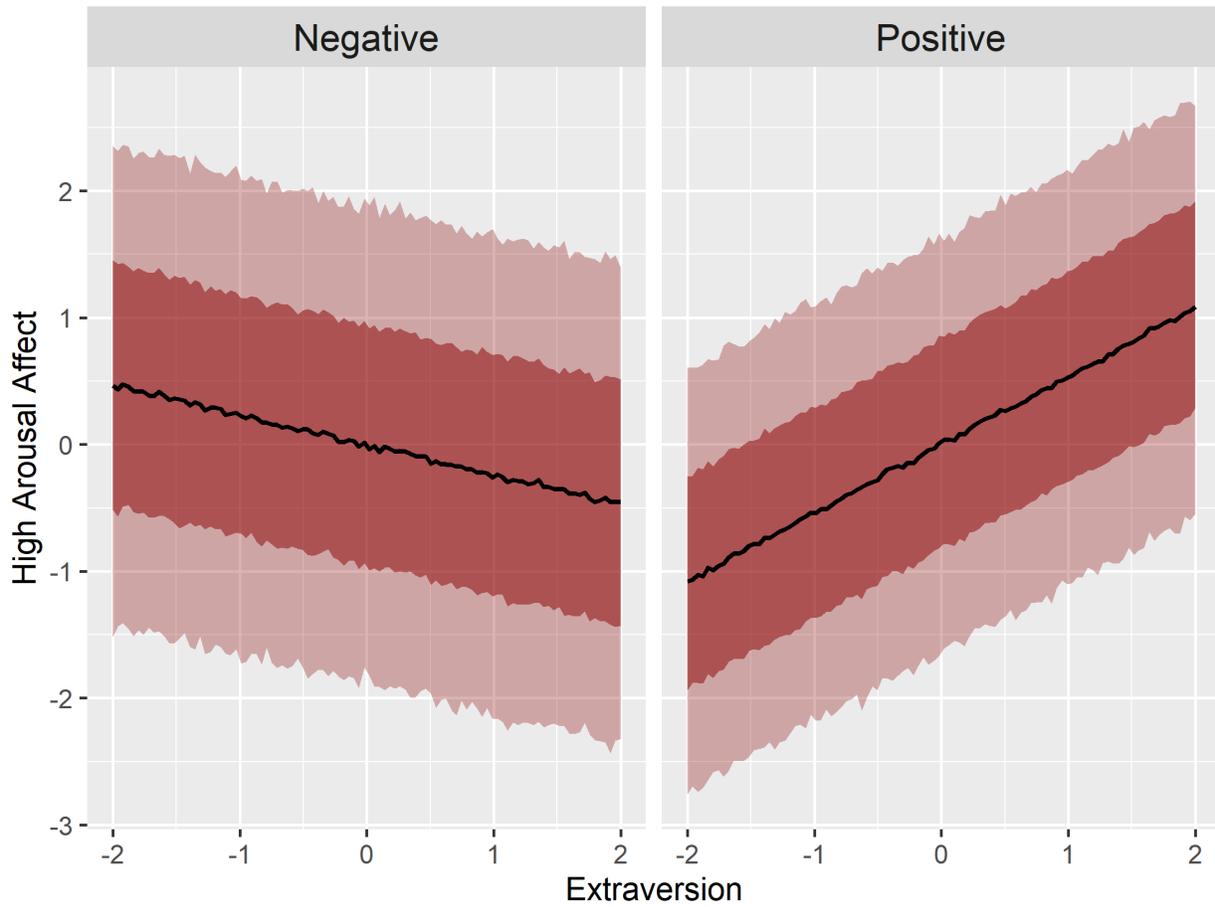


Notes: Black dots represent the posterior means and the red line represents the 95% credible interval.

Posterior predictive simulation.

To further explore the association between extraversion and affect, we performed posterior predictive simulation. Because we have a continuous predictor and continuous outcome, we simulate a *range* of possible extraversion values (-2 – 2 standard units) and visualize the predicted *regression*. Extraversion emerged as a particularly strong predictor of affect in Model 2.1. Follow-up posterior predictive simulation shows this relation more clearly (see Figure 16). We see that for each standard unit increase in extraversion, negative affect is expected to decrease by roughly 0.25 standard units, whereas positive affect is expected to increase by roughly 0.50 standard units. Credible intervals for the 68 percent (dark red) and 95 percent (light red) are shown to illustrate the uncertainty in the simulation.

Figure 16. Posterior predictive simulation predicting positive and negative affect from extraversion.



Notes: Black line represents the mean, dark red band represents the 68% credible interval, and the light red band is the 95% credible interval.

Model 2.1 Summary

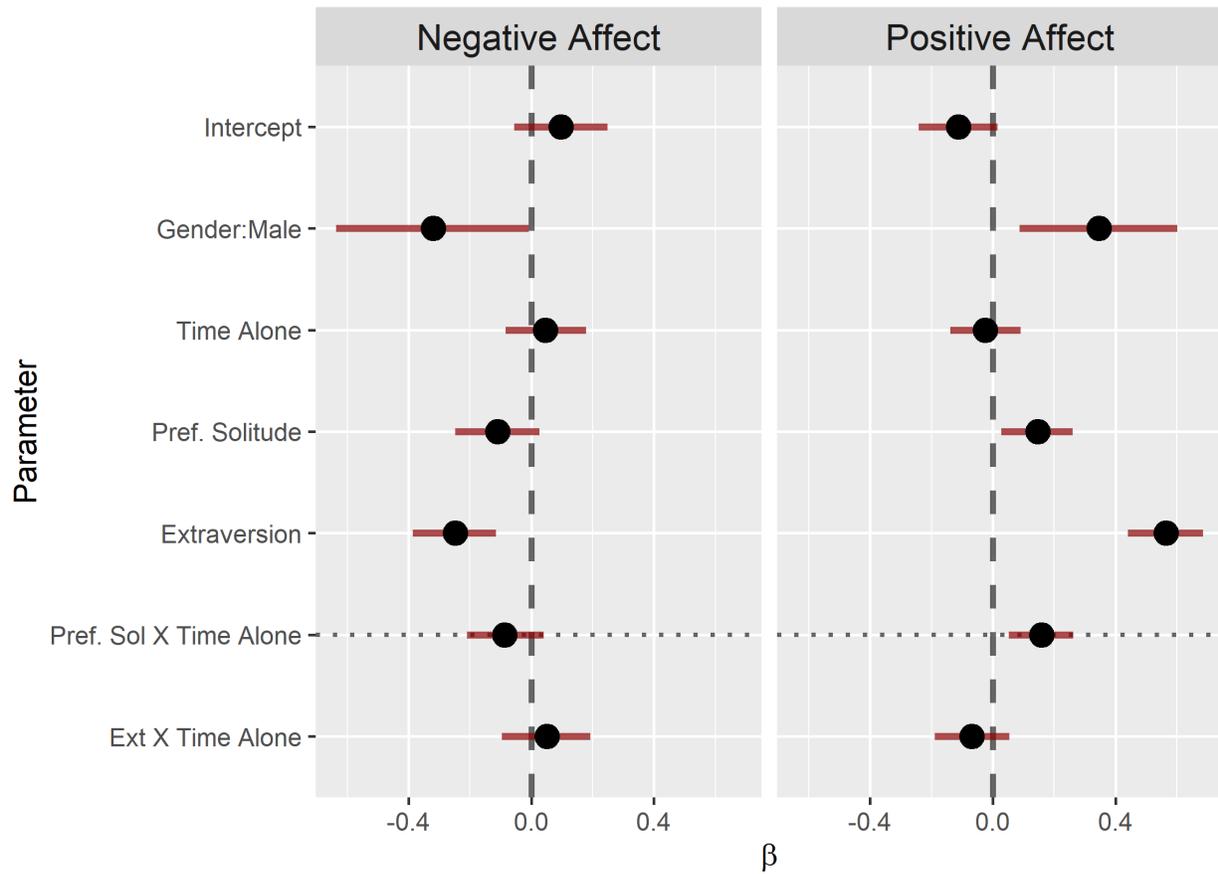
Model 2.1 is the first of a series of models attempting to predict positive and negative affect. It included “baseline” covariates, such as gender, preference for solitude, time alone, and extraversion. Here is what we conclude from Model 2.1:

- Men tend to report higher positive affect and lower negative affect compared to women, although there is still substantial variability in this estimate.
- Consistent with hypotheses, extraversion is positively associated with positive affect and (to a lesser extent) negatively associated with negative affect.
- In contrast to hypotheses, preference for solitude is slightly positively associated with positive affect.

Model 2.2: Interactions with Time Alone

We also want to explore potential interaction effects among time alone, extraversion, and preference for solitude. Model 2.2 includes a Preference for Solitude X Time Alone interaction term and an Extraversion X Time Alone interaction term (in addition to the predictors from Model 2.1). Posterior distributions for model coefficients are displayed in Figure 17. Of note, there is some indication of a Preference for Solitude X Time Alone interaction in the prediction of positive affect. Specifically, those who spend more time alone and have a higher preference for solitude tend to report higher positive affect. This is a small effect, but the credibility interval is fairly concise.

Figure 17. Posterior distributions for coefficients in Model 2.2.

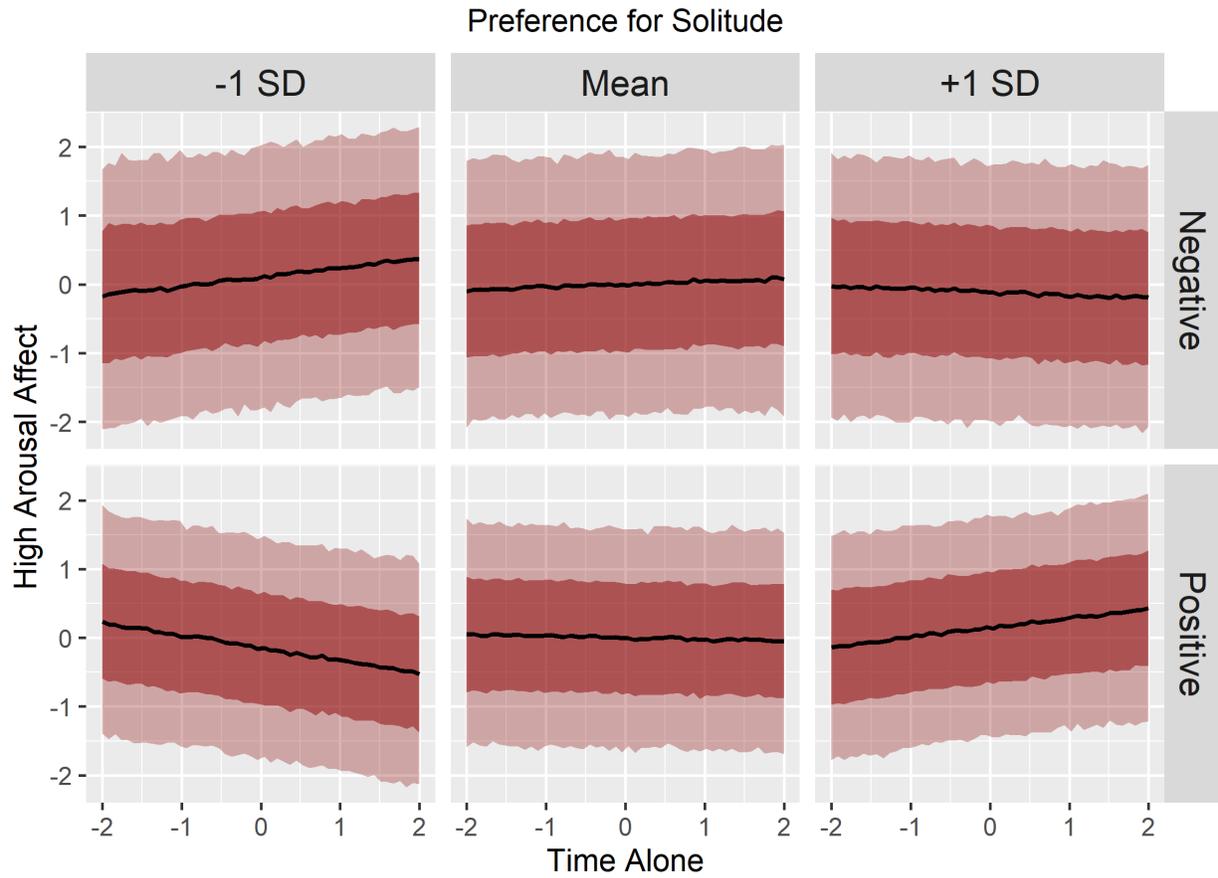


Notes: Black dots represent the posterior mean and the red line represents the 95% credible interval.

Posterior predictive simulation.

We use posterior predictive simulation to understand the Preference for Solitude X Time Alone interaction (see Figure 18). It is clear that among people lower in preference for solitude (-1 SD), time alone is expected to be negatively associated with positive affect and positively associated with negative affect. Among those higher in preference for solitude (+1 SD), this association is reversed, at least in the prediction of positive affect.

Figure 18. Posterior predictive simulation depicting interaction between preference for solitude and time alone in the prediction of positive and negative affect.



Notes: Black line represents the mean, dark red band represents the 68% credible interval, and the light red band is the 95% credible interval.

Model 2.2 Summary

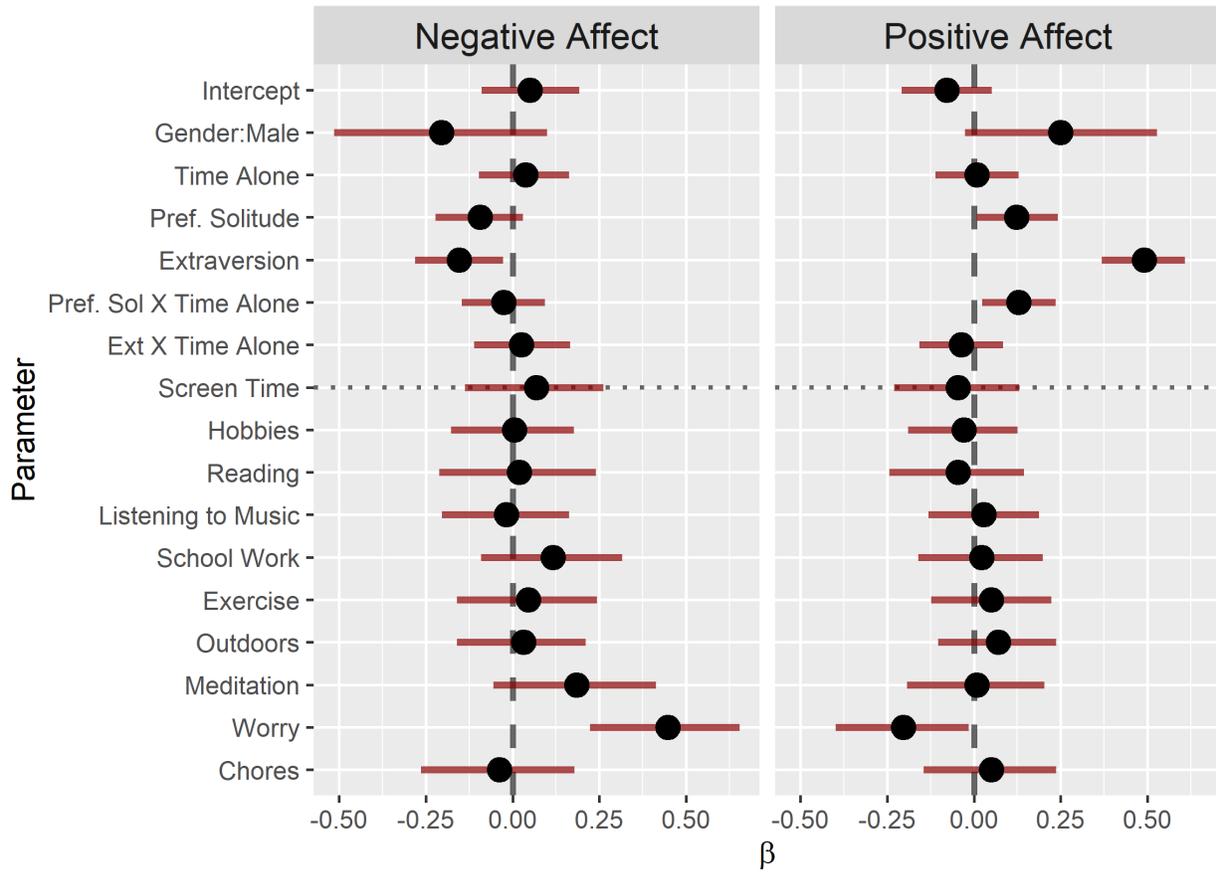
We conclude from Model 2.2 that time alone interacts with preference for solitude to predict affect – in particular, positive affect. Those who prefer solitude and spend more time alone tend to report higher positive affect.

Model 2.3: Predicting Affect from Solitary Activities

We now include the ten transformed solitary activity categories as predictors.²⁴ Coefficients for Model 2.3 are presented in Figure 19. As in Model 2.1-2, extraversion continued to strongly predict positive affect, but its relation with negative affect seems somewhat more uncertain and closer to zero. As for the solitary activities, all of them are fairly uncertain and only one of them, Worry, appears to be reliably above zero, particularly in predicting negative affect. This relation is further demonstrated in the form of a posterior predictive simulation in Figure 20. A standard unit increase in worry is, on average, associated with a 0.50 standard unit increase in negative affect and a 0.25 decrease in positive affect.

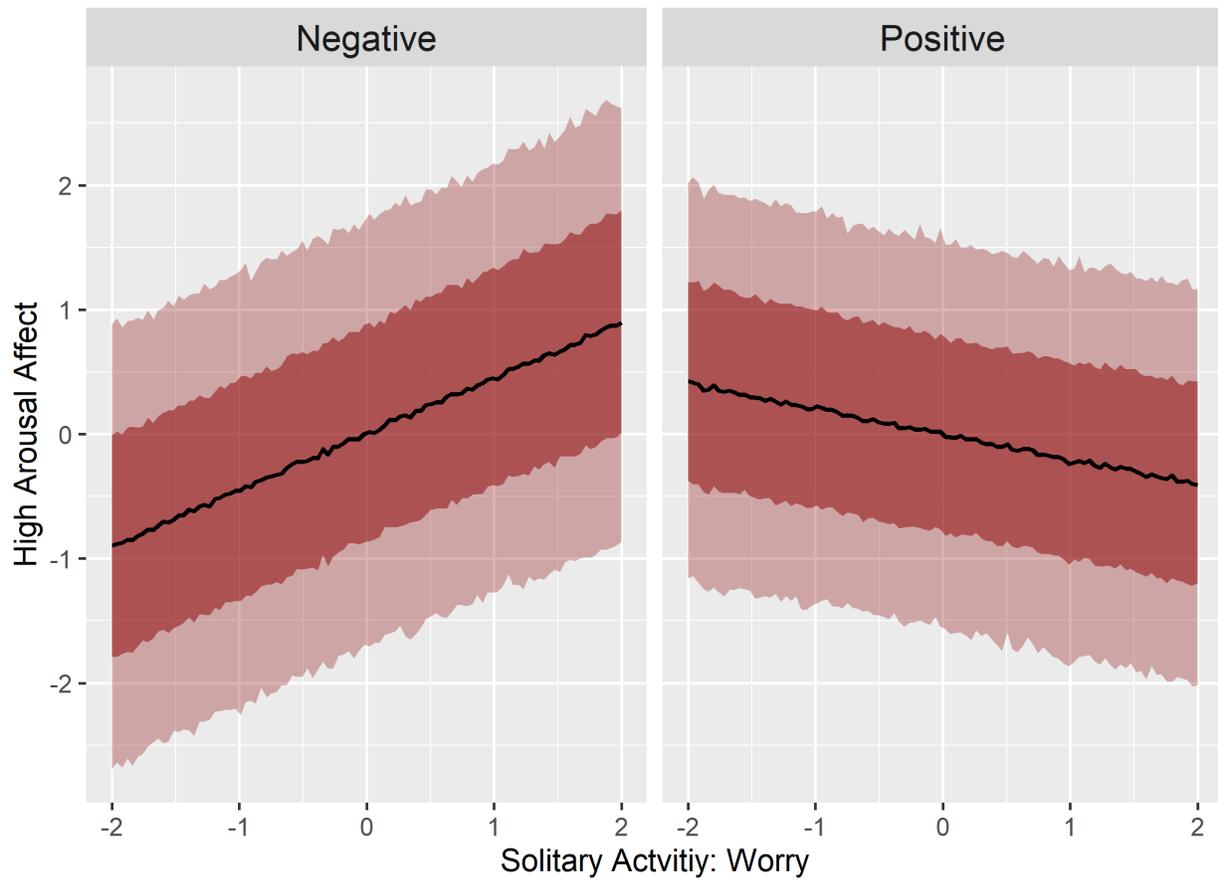
²⁴ Model 2.2 was also run using the raw ranks instead of the transformed activity scores. As can be seen in Appendix B, the results for this model are identical in interpretation to those in the model presented here. We continue with the transformed activity codes because the evidence obtained from the information theoretic algorithm suggested no meaningful gains in information between the middle rankings.

Figure 19. Posterior distributions for Model 2.3 coefficients predicting positive and negative affect.



Notes: Parameters on and below the dotted line are new to Model 2.3 (vs. 2.1 and 2.2). Black dots represent posterior means, red lines represent the 95% credible interval.

Figure 20. Posterior predictive simulation showing the relation between worry and affect (Model 2.3).



Notes: Black line represents the mean, dark red region is the 68% credible interval, and light red region is the 95% interval.

Model 2.3 Summary

Model 2.3 added solitary activities as predictors of affect. We therefore conclude the following about solitary activities:

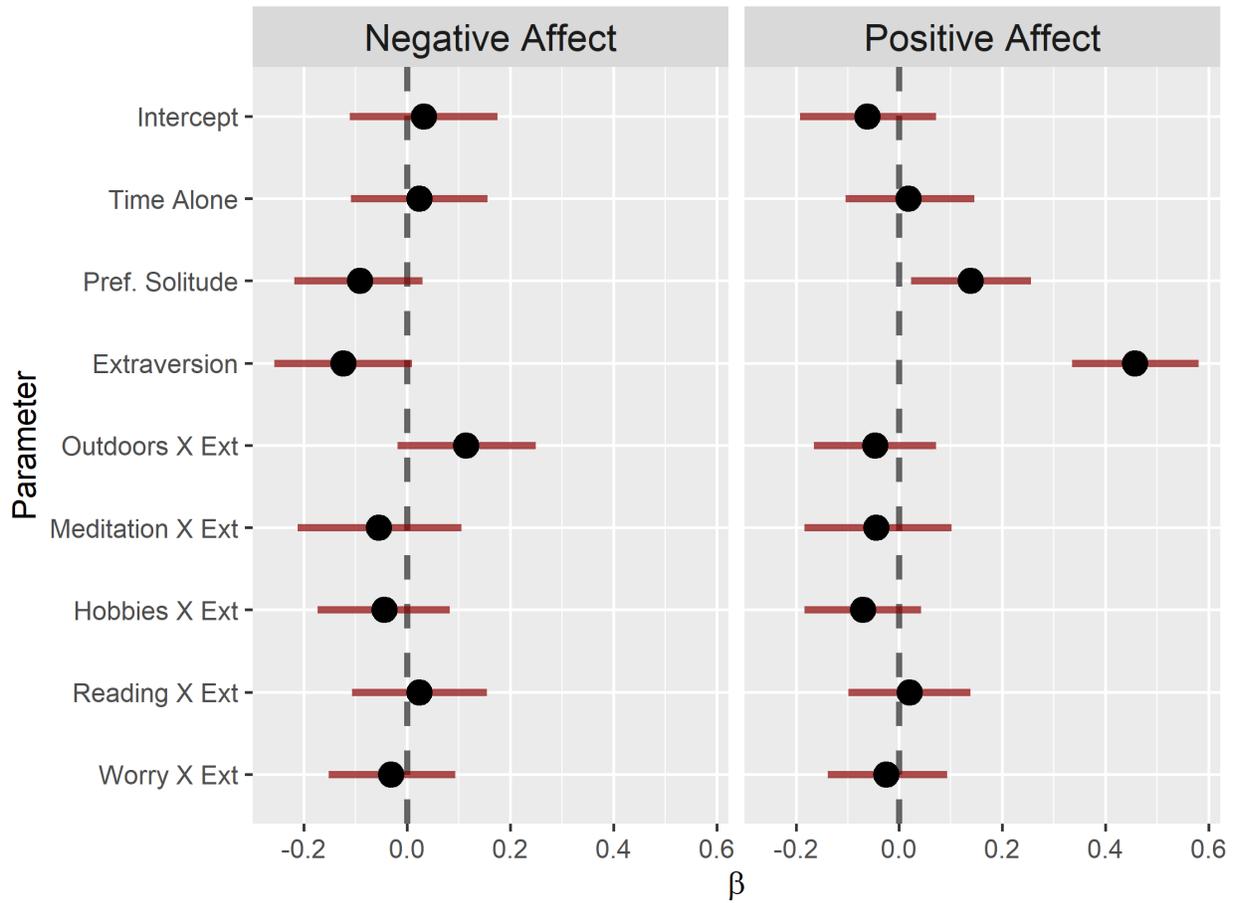
- Most activities have no discernible association with positive or negative affect and there remains considerable uncertainty in their posterior distributions.
- Worry is strongly positively associated with negative affect. The opposite association is observed with positive affect, but to a lesser degree.

Model 2.4: Interactions between Extraversion and Activities

Study 1 and 2 have shown extraversion to be a salient predictor of affect (whether we measure it as valence-arousal or just positive vs. negative). Model 2.3 of Study 2 further revealed that at least one solitary activity, worry, is likely to be reliably associated with negative affect. Although this is on its own is not evidence to suggest possible interactions, it makes sense to explore whether extraversion interacts with different activities. For instance, among those low in extraversion, certain activities could conceivably induce more positive affect. We lack the ability to test this proposition in its entirety, given the cross-sectional nature of the data, but exploring potential interactions could at least stimulate further research on this topic.

As mentioned in the hypotheses, we sought to examine interactions between time alone and these five activities: Hobbies, Outdoors, Meditation, Reading, and Worry. A sample of Model 2.4 coefficients are shown in Figure 21. There appears to be a potential interaction between Outdoors and Extraversion, such that higher extraversion and higher ranking of outdoors is positively associated with negative affect.

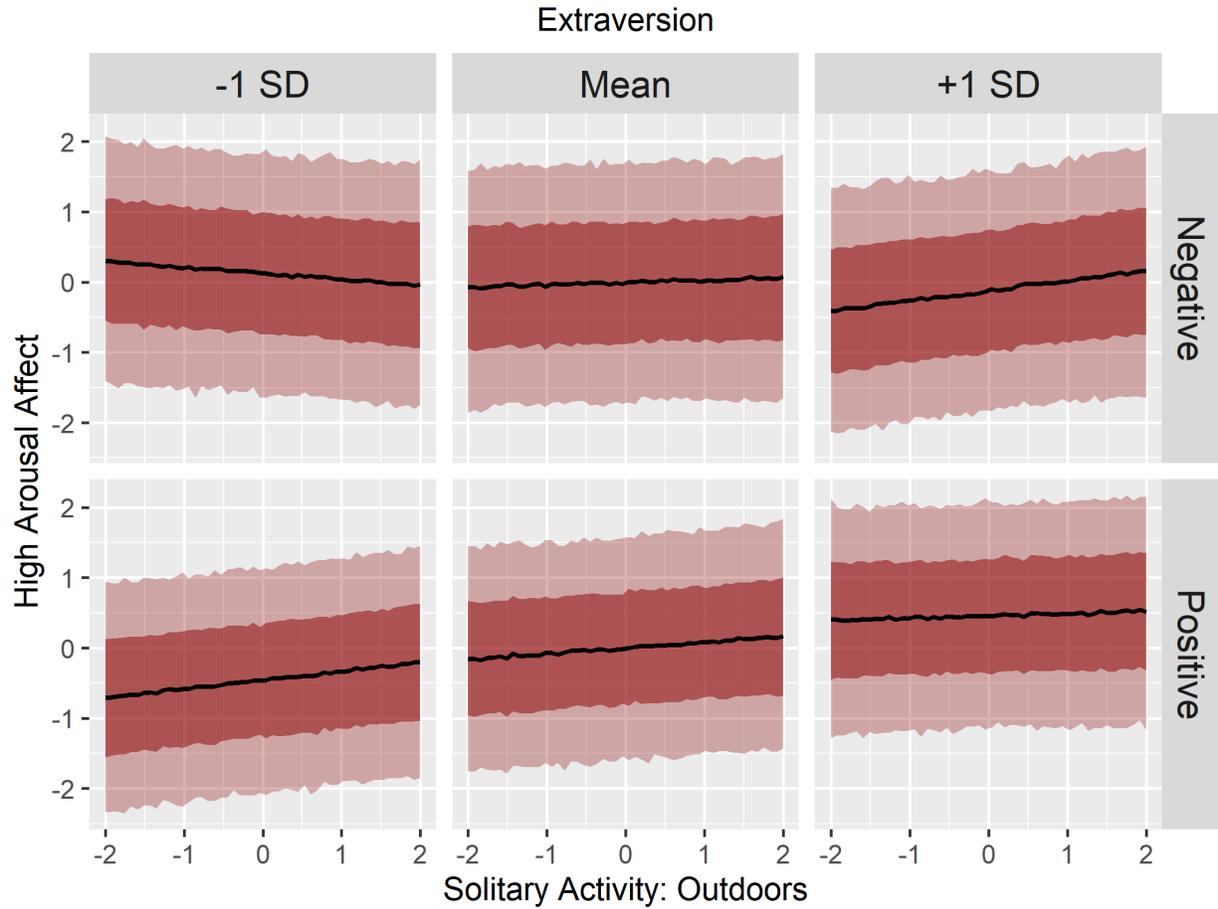
Figure 21. Posterior distributions for Model 2.4 beta coefficients predicting positive and negative affect.



Notes: Only trait variables (e.g., time alone, preference for solitude) and Activity X Extraversion interactions are shown, although the model includes all variables from Models 2.1-2.3. Black dots represent posterior means, red lines represent the 95% credible interval.

Figure 22 shows this relation more clearly using posterior predictive simulation. Among those 1 SD below the mean of extraversion there is a negative association between spending time outdoors and negative affect, whereas among those 1 SD above the mean of extraversion there is a positive association between spending time outdoors and negative affect. For positive affect, there the directionality is reversed, although the effect is relatively subdued. Taken together, based on the size of the credible intervals, these interactions are still only subtle at best.

Figure 22. Posterior predictive simulation showing the interaction between being outdoors and extraversion in the prediction of affect (Model 2.4).



Notes: Black line represents the mean, dark red region is the 68% credible interval, and light red region is the 95% interval.

Model Comparison

We used the same cross-validation approach from Study 1 to evaluate Models 2.1-2.4 (see Table 10). This time, however, model comparison indices unanimously supported Model 2.3, assigning it a weight of 1. Recall that Model 2.3 included trait variables (e.g., time alone, preference for solitude) and all activities, but no interactions. Thus, despite the potential interaction we explored in Model 2.4, it appears that, Model 2.3 is superior in predictive power.

Table 10. Cross validation summary for Models 2.1-4.

Model #	WAIC (SE)	LOO	Weight
2.1	1144.1 (27.38)	-573.2	0
2.2	1137.7 (25.97)	-570.2	0
2.3	1108.7 (25.80)	-556.5	1
2.4	1120.8 (25.31)	-563.2	0

Notes: Model 2.1 includes time alone, extraversion, gender, preference for solitude. Model 2.2 adds interactions with time alone. Model 2.3 adds solitary activities. Model 2.4 adds interaction terms for each activity and extraversion. WAIC = Watanabe-Akaike Information Criteria; LOO = Leave-One-Out Cross Validation; Weight = a rough estimate of how much “trust” we should put in each model given its scores on WAIC, LOO, and comparisons with other models (closer to 1 = preferred model).

Study 2 Discussion

In Study 2, we explored how trait variables related to solitude (e.g., time alone, preference for solitude, extraversion) and activities while alone were related to high arousal positive and negative affect. Although the associations among time alone, preference for solitude, and extraversion have been well-established (Wilt et al., 2012), including solitary activities represented a relatively novel direction for this line of research. Overall, results indicated that preference for solitude moderates the association between time alone and affect. However, solitary activities seem to have little direct or moderating effects in relation to time alone and affect.

Hypothesis 1: Associations with Time Alone and Affect

Although the adjusted design of Study 2 made it difficult to rigorously test the deactivation effect, we can gain some insight into this process by looking at the association between time alone and high arousal affect. Hypothesis 1 stated that, based on the deactivation effect, people who spent more time alone in a given week would report lower high arousal affect that week. Somewhat surprisingly, there was no evidence in support of this hypothesis as time alone was neither associated with positive nor negative affect. This is weak evidence *against* the deactivation effect. It is only considered “weak” because the current study is cross-sectional and focuses on overall time alone and affect instead of specific emotional events as Study 1 did. Still, if the deactivation effect were strong, we would expect to find people who spend more time alone would on average report lower positive and negative arousal, which we did not find here.

Thinking beyond the deactivation effect, the current findings are somewhat inconsistent with what previous research says about the link between time alone and overall affect. As mentioned earlier, there have been several studies supporting a negative association between

time alone and positive affect (see Coplan et al., 2018 for a review). In the end, it is likely that the current study is too limited to adequately parse the role of time alone in our emotions.

Hypothesis 2: Extraversion, Preference for Solitude and Affect

Hypothesis 2 un-controversially stated that extraversion would be positively associated with positive affect and negatively associated with negative affect. We found strong evidence in support of this hypothesis and we also found that extraversion was negatively associated with time alone. These findings corroborate extensive cross-sectional (Hills & Argyle, 2001), longitudinal research (Wilt et al., 2012), and experimental research (Zelenski et al., 2013).

However, in contrast with expectations, there was a weaker, yet fairly reliable, negative association between preference for solitude and negative affect and a similarly weak positive association with positive affect. This is surprising, given that previous studies have found reverse associations with preference for solitude and affect (Goossens, 2006; Teppers et al., 2013), with higher preference for solitude tending to impart lower happiness and higher stress and anxiety (Wang et al., 2013). However, it is possible that including extraversion and time alone in the model helped to isolate the unique association between preference for solitude and affect. For instance, some research has suggested that much of the negative implications of preference for solitude are explained by personality (e.g., extraversion) and behavioural (e.g., time alone) covariates (Coplan, Hipson, et al., 2019; Goossens, 2014). This also fits conceptually with preference for solitude, which is distinct from concepts like social withdrawal and shyness (Coplan & Weeks, 2010).

Hypothesis 3: Interaction between Time Alone and Preference for Solitude

The third hypothesis was that time alone would interact with preference for solitude in the prediction of positive and negative affect. More specifically, it stated that among people who

prefer solitude more, time alone would be more strongly positively associated with positive affect and more negatively associated with negative affect. We found some evidence to support this, at least in the prediction of positive affect. Posterior predictive simulations showed that among those low in preference for solitude, time alone is negatively associated with positive affect, whereas among those high in preference for solitude, time alone is positively associated with positive affect. Those who prefer solitude may find that it brings them satisfaction and gives them the opportunity to do things they would not be able to do in a large group (Burger, 1995). This is also consistent with research suggesting that people who prefer solitude and get enough of it are more satisfied than those who prefer solitude but do not get to spend enough time alone (Coplan, Hipson, et al., 2019).

Although this is an interesting finding and is consistent with previous work (e.g., Lay et al., 2018), there are now some conflicting results in Study 1 versus Study 2. This inconsistency is most likely due to the different approach in measuring time alone and affect. Study 1 focused on these relations at the situation level (momentary affect, momentary time alone, trait preference for solitude) and in response to an emotional event; whereas Study 2 was more so at the trait level (weekly time alone, overall affect, trait preference for solitude) and not tied to emotional events. Solitude may not be particularly conducive to increasing happiness following an emotional event, even if one enjoys solitude – but spending more time alone on average and enjoying solitude may overall increase positive affect.

Hypothesis 4: Solitary Activities and Affect

There have been surprisingly few attempts to document the *frequency* of university students' solitary activities. Although the current study does not provide daily reports of activities, comparative frequencies can be inferred from the retrospective reports. For example,

university students ranked screen time activities over all other activities, which is consistent with the increasing rate of screen-related activities among youth and adolescents (Atkin et al., 2014; Hipson, Coplan, et al., 2021; Knell et al., 2019). However, we still found evidence of diversity in university students' solitary activities, with schoolwork, listening to music, and reading for pleasure ranking among the most frequently listed activities.

It was further hypothesized that intrinsically motivated activities (i.e., hobbies, reading for pleasure) would be positively associated with positive affect, but no evidence was found support this postulation. On the one hand, this is not entirely surprising, as there is no previous evidence suggesting a causal link between activities like hobbies and well-being, and correlational studies tend to only include hobbies as an indicator of well-being rather than a predictor of well-being (Boelhouwer & Stoop, 1999). On the other hand, we might expect that spending time alone engaged in activities that are theorized to be rewarding and stimulating (see Kleiber et al., 1986) would be better than being alone watching TV.

There are a few reasons why this study may have failed to find this hypothesized association. First is that activities do not neatly fit into intrinsically/extrinsically motivated categories. We often think of hobbies as being more intrinsically motivated, but they can be externally imposed too, if, for example, one does a hobby because their parents or friends encouraged them to (Graef et al., 1983). Alternatively, screen-based activities, such as video games, coding, and watching a beloved series on Netflix, can offer a great sense of fulfillment (LeBlanc et al., 2017). Second, we should question that assumption that doing more intrinsically motivated activities often is enough to increase one's well-being. For example, one may spend much of their day doing things they want to do, all the while not gaining fulfillment from these activities. Finally, the lack of cross-sectional links between activities and well-being is by no

means definitive in suggesting that what we do while alone affects how we experience our time alone. For instance, spending one's time alone doing hobbies may make that time more enjoyable, but it is unlikely that this translates into increased overall well-being. It may be that the benefits of different solitary activities are fleeting. In other words, we must distinguish between the *hedonic* and the *eudaemonic* benefits of solitary activities (see General Discussion).

Notwithstanding, one activity emerged as being robustly associated with affect: worrying/ruminating. Not surprisingly, those who reported worrying more while alone tended to report higher negative and lower positive affect. In a sense, this finding is somewhat tautological because worrying is conceptualized as a negative emotion (or least inherent to negative emotion). Moreover, it seems perfectly reasonable that someone who tends to worry would also experience other negative emotions (Nolen-Hoeksema et al., 2008). Without a comparison group, we do not even know if this association is limited to worrying as a solitary activity, and it seems unlikely that this would be the case – worry in any situation is likely to involve negative emotion. For now, we can claim there is evidence that those who tend to worry while alone tend to be less happy, but we unfortunately do not know whether spending time alone *and* worrying causes unhappiness.

There is good reason to suspect that the causal direction goes the other way too – that people who are feeling negative emotions tend to worry, perhaps in a solitary context. Research suggests that after experiencing a negative event, people tend to engage in ruminative thought (Liu & Thompson, 2017; Nolen-Hoeksema et al., 2008; Wegner & Zanakos, 1994). An especially common type of negative thinking following unpleasant events is counterfactual thinking – reimagining how the event could have gone differently (Roese & Olson, 1997). These findings suggest that negative events are a precursor to worry. But is there evidence that negative

events could trigger worrying while alone? Currently, there is only indirect evidence of this: Ren et al., (2020) found that when people experience ostracism (a negative event), they are more likely to subsequently spend time alone. It is then conceivable that solitude induced by these negative conditions would involve worrying and rumination.

Hypothesis 5: Interactions between Solitary Activities and Time Alone

The previous hypothesis was about main effects linking solitary activities to affect – akin to asking whether certain activities are associated with positive and negative emotion, regardless of how much time one actually spends alone. This final hypothesis postulated that the link between time alone and affect would vary as a function of activity. To this effect, we found some evidence of a small interaction between being outdoors and extraversion in predicting affect. Specifically, those lower in extraversion had a slight negative association between being outdoors and negative affect, whereas those higher in extraversion had a slight positive association with negative affect (an even smaller, but inverse version of this was found for positive affect).

We should exercise some caution in interpreting this interaction too strongly because: (1) it is quite uncertain and weak; and (2) the model including this interaction is less predictive than the simpler model, it is worth noting that it is consistent with some research. For one, several studies have found that being alone in nature is pleasant and restorative (Berman et al., 2008; Herzog et al., 1997; Kaplan, 1995; Korpela et al., 2018). As well, people who want to spend time alone often do so because they claim that solitude will help them relax (Long et al., 2003; Nguyen et al., 2019). Therefore, it is plausible that those higher in introversion may seek time alone outdoors because it is calming and restorative, whereas those higher in extraversion may find this solitary outdoor time unpleasant. One problem with this interpretation is that the

literature on nature and restorativeness has yet to convincingly demonstrate that solitude is a necessary condition for reaping nature's supposed restorative properties. Experiments conducted in simulated environments suggests that people might be more likely to experience nature as more restorative while alone, but they would also report feeling less safe (Staats et al., 2004). Further experimental evidence is needed to establish this causal interpretation.

Study 2 Limitations and Conclusion

In summary, Study 2 provided some new insights into how various solitary activities are associated with affect. It was somewhat surprising that most of the solitary activities investigated had very little association or were not associated at all with affect. Only worry emerged as a reliable predictor of affect. As with Study 1, we were again limited in our conclusions due to the single-time point, cross-sectional nature of this study (as mentioned earlier – the emergence of the COVID-19 pandemic precluded the collection of the intended follow up data). In retrospect, Study 2 is perhaps even more limited than Study 1 because it did not even use a pre-post assessment of affect. Future research will need to implement an experience sampling approach to truly understand the impact of different solitary activities on people's emotional states. Indeed, the use of experience sampling is necessary if we are to determine how context relates to emotion because both are constantly changing in time.

Study 3: Experience Sampling of Everyday Social Context, Emotion, and Emotion Regulation

The overarching goal of this dissertation is to understand how solitude impacts our emotions and the way we manage our emotions. Study 3 aims to shed light on both aspects of this goal. The first objective of Study 3 is to examine whether social context (alone vs. with others) impacts how people regulate their emotions (i.e., which emotion regulation strategy they

choose). Previous research suggests that emotion regulation is highly context dependent – varying as a function of our social situation (English et al., 2017), and perhaps even which emotion we are feeling. The second objective of this study brings us back to the central question of whether solitude impacts how our emotions change over time. Solitude may impact which emotion regulation strategy we use, but it may also influence how our emotions change over the course of an emotional event. Specifically, this study will look at whether being alone (vs. being with others) is associated with change in emotion following an emotional event. Due to the nature of the data, we modify our focus somewhat to examine change in emotion intensity for a set of discrete emotions (anxiety, anger, sadness) rather than change in affect dimensions.²⁵

In contrast to Studies 1 and 2 which were cross-sectional and retrospective, the data collected for Study 3 used an experience sampling approach. This offers three major advantages: (1) the use of repeated assessments of the same participants allows us to partition the variance into participant-specific and error variances; (2) we can compare the effects of baseline trait measures and measures with repeated assessments; and (3) there is less concern of recall bias because participants are reflecting on recent events.

Study 3 Hypotheses

Hypotheses related to emotion regulation strategy selection.

- 1) Those who are alone will be more likely to use rumination, distraction, and relaxation, whereas those who are with others will be more likely to use suppression (English et al., 2017). There will be no effect of social context on reappraisal or engagement.

²⁵ The author was granted permission to use this data as part of a collaboration with another researcher. The full data set includes many more variables than are used in this dissertation. However, part of the agreement to use the data involved a careful decision over which subset of variables would be used. Data privacy agreements also preclude the sharing of experimental materials as appendices.

- 2) Social avoidance will be positively associated with the probability of selecting rumination and suppression. This is expected because of evidence that highly socially *anxious* individuals (conceptually similar to socially avoidant) employ suppression more often than reappraisal (Kivity & Huppert, 2019), which is consistent with the broader pattern of anxiety associated with more suppression tactics (Aldao et al., 2010).
- 3) People will be more likely to use reappraisal when they are sad and anxious (Rivers et al., 2007). There are no specific hypotheses for anger as most research shows that people use situation modification strategies when angry, and these are not included in the current study.

Hypotheses related to change in emotion intensity.

- 4) There will be a deactivation effect, such that being alone will be associated with a stronger decrease of emotion intensity compared to being with others. Here, we are using emotion intensity as a proxy for arousal.
- 5) There will be a Social Context X Strategy interaction. Specifically, those who are alone and ruminate will experience a greater increase in emotion intensity compared to those who are with others and ruminate or use other strategies (Rose et al., 2002). Those who are alone and use distraction will experience diminished Time 2 emotion intensity compared to those who are with others and use distraction.

Participants and Procedure

Participants were $N = 185$ undergraduate introductory psychology students (159 female, 25 male, 1 non-binary) at a mid-sized university in Canada with a mean age of 19.01 (SD = 3.21) years. Data was not collected on participant ethnicity.

Initial visit.

All procedures were approved by the Queen's General Research Ethics Board (GREB). Participants registered online and were emailed a consent form. After providing consent they attended an in-person session where they completed demographics and the social avoidance questionnaire. Participants then downloaded the MetricWire experience sampling app and were trained how to use the app by a research assistant.

Experience sampling.

Starting the day after their initial visit, participants were prompted by the MetricWire app to answer a brief series of questions regarding negative emotions, social context (alone or with others), emotion regulation strategies, and other variables not of interest in this dissertation. Participants could complete up to a total of 42 prompts. Every day at 11:00am, 4:00pm, and 8:30pm for 14 days (42 prompts). Each prompt took approximately 1–2 minutes to complete and participants were given a 90-minute completion window to accommodate for their varying schedules. Research assistants monitored the fidelity of prompt completion every evening and sent reminder emails to those who missed any prompts (see Colasante et al., 2020; Gabriel et al., 2019 for detailed overviews of this methodology).

Measures**Experience sampling measures.**

At the beginning of each prompt, participants were asked to report the strongest negative emotion experienced since their last prompt and were given the forced choices of anxiety, sadness, or anger and asked to indicate the strength of this emotion on a 100-point scale (1 = “not intense at all, I barely noticed it” - 100 = “the most intense”; see Kuppens et al., 2008 for an empirical example of this approach). We refer to this strongest negative emotion as the

'event'. Participants were then asked whether they were alone or with others when the event occurred. We also averaged these responses for each participant to create an 'average alone' variable, which represents a tendency to be alone versus with others.

Participants were also asked which emotion regulation strategy they used the most during the event. They chose from six descriptions, each representing the following strategies: *Engagement* ("Showed my feelings"), *Suppression* ("Pretended I was not upset"), *Reappraisal* ("Looked at the event from a different perspective"), *Distraction* ("Engaged in something else to keep busy"), *Rumination* ("Continually thought about what was bothering me"), and *Relaxation* ("Tried to slow my heart rate and breathing") (De France & Hollenstein, 2017). Finally, using the same 1-100 scale, participants rated how they felt after they had used their chosen emotion regulation strategy (Time 2 emotion intensity).

Trait social avoidance.

Participants completed the 8-item *Behavioral Social Avoidance Scale* (Ottenbreit & Dobson, 2004). They rated each item (e.g., "I tend to make up excuses to get out of social activities" on a 5-point scale (1 = not at all true for me - 5 = extremely true for me; $\alpha = .87$, in the current study). This scale has been found to correlate with measures of depression and anxiety (Ottenbreit & Dobson, 2004).

Data Preparation and Cleaning

The nature of this study required a different approach to data cleaning compared to Studies 1 and 2. We excluded prompts for which participants reported the lowest possible intensity score for their negative emotion (i.e., '1 – not intense at all, I barely noticed it') because such scores implied no need for regulation ($n = 377$ prompts). In cases of missingness, imputation was only performed on missing emotion regulation strategies. The reason for this

was that it quickly became unwieldy to impute the categorical predictors in addition to the multinomial outcome. Given that strategies were the focus, it made sense to focus imputation efforts on this variable. Moreover, missingness was substantially lower on many of the other covariates, and there was no missingness for Time 1 emotion. Our final sample size for analysis was $N = 168$ participants ($N_{\text{prompts}} = 5,237$, 88% female).

Results

Descriptive Statistics

Descriptive statistics are presented in Table 11. We note that Time 1 Emotion is, on average, higher than Time 2 Emotion. We also note that participants reported being alone 41% of the time. Pairwise correlations are presented in Table 12.

Table 11. Descriptive statistics for variables in Study 3.

	Mean	SD	Min	Max
t1 Emotion	42.30	24.60	2.00	100.00
t2 Emotion	35.84	24.32	1.00	99.00
Social Avoidance	1.95	0.66	1.00	4.13
Average Alone	0.41	0.25	0.00	1.00
Alone	0.41	0.49	0.00	1.00
Suppression	0.14	0.34	0.00	1.00
Relaxation	0.16	0.37	0.00	1.00
Reappraisal	0.09	0.29	0.00	1.00
Rumination	0.17	0.38	0.00	1.00
Distraction	0.27	0.44	0.00	1.00
Engagement	0.17	0.37	0.00	1.00

Notes: Alone, Suppression, Relaxation, Reappraisal, Rumination, Distraction, and Engagement, are all binary variables. Thus, the descriptive statistics for these variables are proportions.

Table 12. Pairwise correlation coefficients for variables in Study 3.

	t1 Emotion	t2 Emotion	S. Avoidance	Alone	Suppression	Relaxation	Reappraisal	Rumination	Distraction
t1 Emotion	-	-	-	-	-	-	-	-	-
t2 Emotion	0.88***	-	-	-	-	-	-	-	-
Social Avoidance	0.18*	0.15	-	-	-	-	-	-	-
Alone	-0.04	-0.14	0.22**	-	-	-	-	-	-
Suppression	0.03	-0.06	0.15	0.09	-	-	-	-	-
Relaxation	-0.08	-0.16*	-0.14	0	-0.33***	-	-	-	-
Reappraisal	-0.08	-0.1	-0.13	0.12	-0.07	-0.1	-	-	-
Rumination	0.13	0.2**	0.2**	-0.02	-0.06	-0.3***	-0.13	-	-
Distraction	-0.01	0.02	0.02	0.04	-0.26***	-0.25**	-0.25**	-0.25**	-
Engagement	0.01	0.09	-0.12	-0.22**	-0.28***	-0.08	-0.22**	-0.19*	-0.19*

Notes: Alone, Suppression, Relaxation, Reappraisal, Rumination, Distraction, and Engagement, are all binary variables. Thus, the descriptive statistics for these variables are proportions. Average Alone is omitted because its pattern of correlations is identical to Alone.

Study 3 Models Overview

There are five models in Study 3. The first two models, 3.1 and 3.2, focus on predicting emotion regulation strategy selection. Specifically, Model 3.1 is a baseline, intercept-only model that establishes the frequency of strategy selection. Model 3.2 expands this framework to include covariates; namely, social context. Models 3.3, 3.4, and 3.5 focus on predicting change in emotion as a function of social context and emotion regulation strategy, where 3.3 includes baseline predictors like Time 1 emotion and social avoidance, 3.4 includes social context and strategies, and 3.5 includes interactions among these variables.

Model 3.1: Probability of Choosing a Strategy

We begin with a simple intercept-only (i.e., no covariates) model where the goal was to infer the probability of choosing a particular strategy. However, we also incorporate varying intercepts for each participant. As in Model 1.4 where we modelled the probability of being in a particular social context, which was a nominal variable, we here use multinomial regression to model the probability of selecting one of the six strategies. In this case, the strategy Engagement serves as the reference because it pertains to “showing one’s emotions”, which could be seen as applying minimal regulatory effort. In the end, it actually makes little difference which is chosen as the reference because the model predictions do not change. It is only the coefficients that take on different values, but because they are log-odds (which can be expressed a probabilities and so sum to one) the information is comparatively identical across different choices of reference (Koster & McElreath, 2017). In other words, the model predictions are invariant to the choice of reference category.

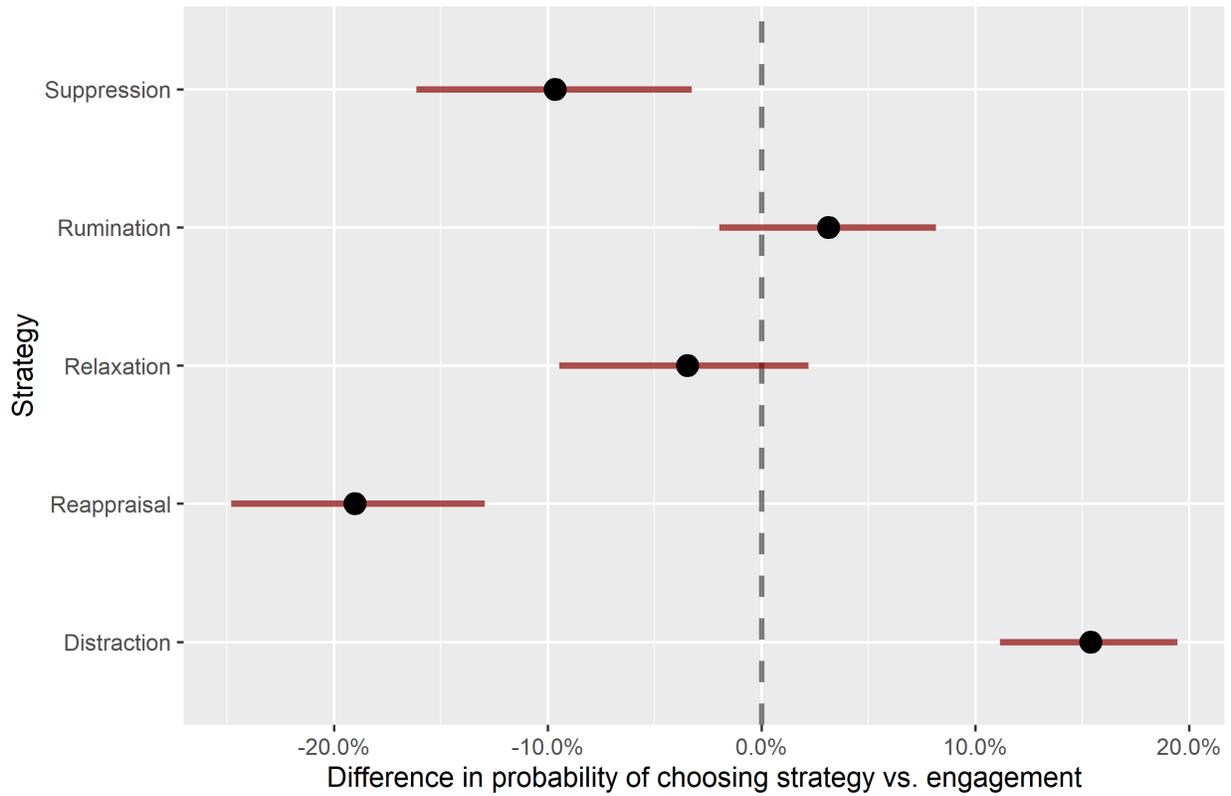
Where this model deviates from that in Study 1 is in the introduction of varying intercepts and slopes parameters. In this study we have observations nested within participants, so we must account for within-participant variance. The model takes on the mathematical form:

$$\begin{aligned}
 y_i &\sim \text{Categorical Logit}(\mathbf{p}) \\
 p_1 &= \log\left(\frac{k_i = 1}{K}\right) = \beta_1 + v_{[1,i]} \\
 p_2 &= \log\left(\frac{k_i = 2}{K}\right) = \beta_2 + v_{[2,i]} \\
 &\vdots \\
 p_{K-1} &= \log\left(\frac{k_i = K-1}{K}\right) = \beta_{K-1} + v_{[K-1,i]} \\
 v_{[k,i]} &\sim \text{Multinormal}(\mathbf{0}, \mathbf{\Omega})
 \end{aligned}
 \tag{7}$$

Much of this is similar to Model 1.4. The main difference is the addition of a varying intercept/slope term, $v_{[k,i]}$, capturing the participant specific deviation from the “fixed” intercepts and slopes *for each* of the $K - 1$ strategies. We draw these varying effects from a multinormal distribution with mean vector 0 and covariance matrix $\mathbf{\Omega}$. The covariance matrix allows the probability of each K strategy to covary with the other strategies within each participant. This is important because we would expect that a person would tend to use similar strategies over time.

Parameter means and 95 percent credibility intervals are presented in Figure 23. We see that distraction is the most probable strategy, being roughly 10-20 percent more likely to be chosen over engagement. Conversely, we see that reappraisal is the least probable strategy, being about 15-30 percent less likely to be chosen than engagement.

Figure 23. Coefficients for Model 3.1 showing the estimated probability of selecting a particular emotion regulation strategy



Notes: Original log-odds were converted to probabilities for interpretability. Values greater than 0 correspond to an increase in the probability compared to choosing engagement, whereas values less than 0 correspond to a decrease in probability compared to choosing engagement.

Model 3.2: Effect of Social Context and Emotion Context on Strategy Selection

We now include a matrix of covariates to model as predictors of emotion regulation strategy selection. These covariates include gender, Time 1 emotion intensity, trait social avoidance, and, importantly, social and emotion contexts. Recall that social context is the measure of *Alone vs. With Others* and emotion context is the measure of which discrete emotion the participant reported (anger, sadness, or anxiety).

Parameter estimates for Model 3.2 are presented in Figure 24. First, it is clear that most strategies become at least marginally more likely (compared to engagement) in the context of solitude. However, being alone seems to be particularly associated with an increase in probability of using distraction, rumination, and (to a lesser extent) relaxation in comparison to engagement. Note that these associations hold even when average alone is included as a predictor in the model. Indeed, tendency to be alone seems to add very little to the model and the estimate around this coefficient is highly uncertain.

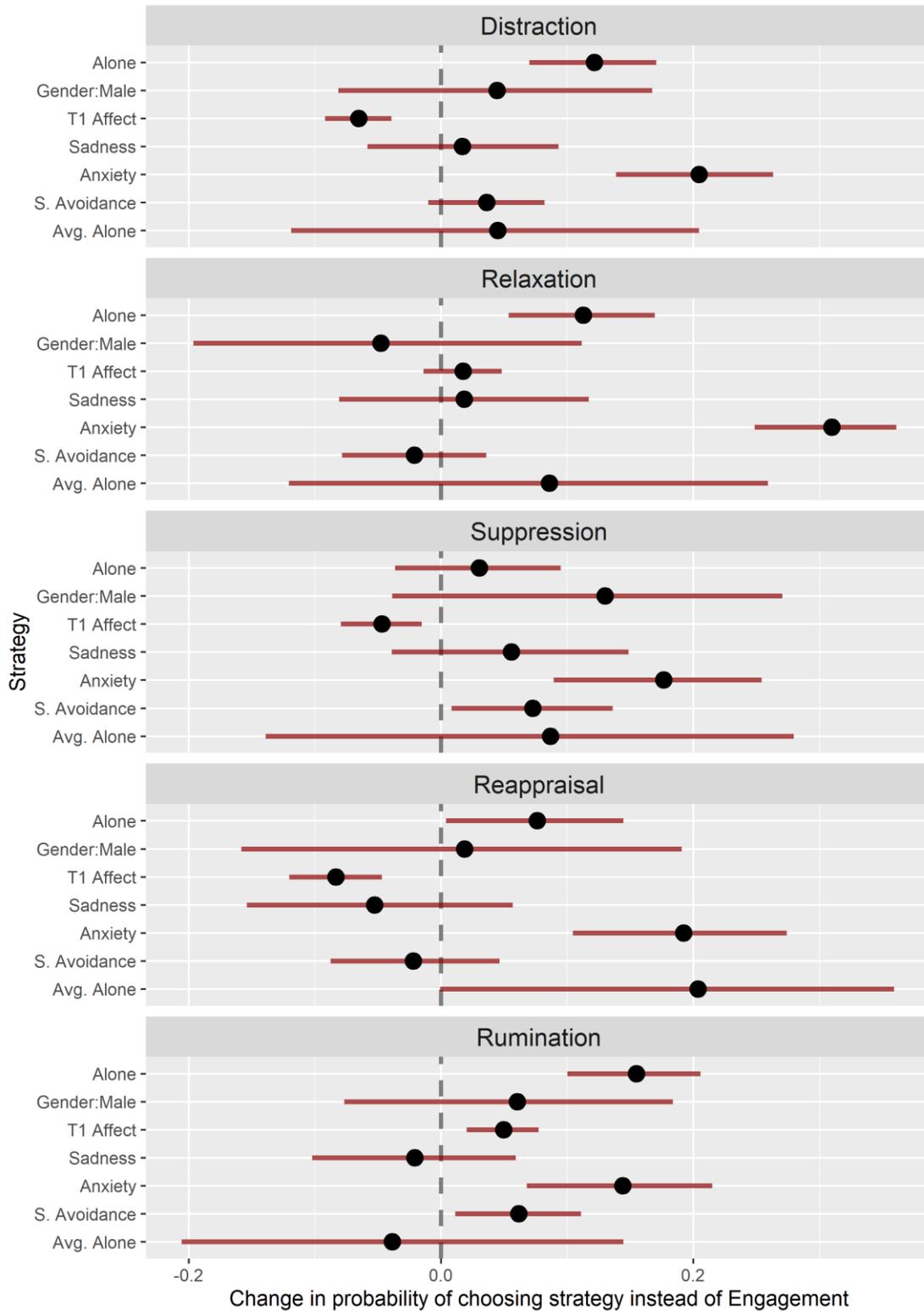
We also note a great deal of uncertainty regarding the effect of gender, which we can probably attribute to the disproportionate ratio of women to men in this sample. There is some evidence to suggest that men are more likely to suppress their emotions (compared to engagement), but the 95% credible interval places this difference anywhere between ~30-2%. Estimates for the effect of Time 1 affect, in contrast, are noticeably more certain. We can see that distraction, suppression, and reappraisal become less probable compared to engagement when Time 1 affect is higher. Conversely, rumination becomes more likely as Time 1 affect increases.

Emotion context (anger, sadness, anxiety) was dummy-coded with anger as the ‘baseline’ category, so when looking at the coefficients for sadness and anxiety note that these are to

interpreted in comparison to the effect of anger. Focusing first on the effect of sadness vs. anger, we see very little evidence to suggest that experiencing sadness influences strategy selection. In contrast, anxiety is quite strongly associated with selecting any strategy other than engagement. Experiencing anxiety (instead of anger) is associated with an increase in the probability of choosing all strategies (relative to engagement). Experiencing anxiety greatly increases the probability of choosing relaxation, specifically, to the tune of ~25-37.5 percent.

Finally, it is unclear from the coefficients whether social avoidance is associated with strategy selection. Compared to the reference category, social avoidance appears to be positively associated with an increase in the probability of selecting rumination and suppression, but we need to visualize the posterior predictive distribution to ensure that this is not an artifact of the reference category.

Figure 24. Posterior distributions for coefficients in Model 3.2.



Notes: Black dots are posterior means and red lines are 95% credible intervals.

Posterior predictive distribution.

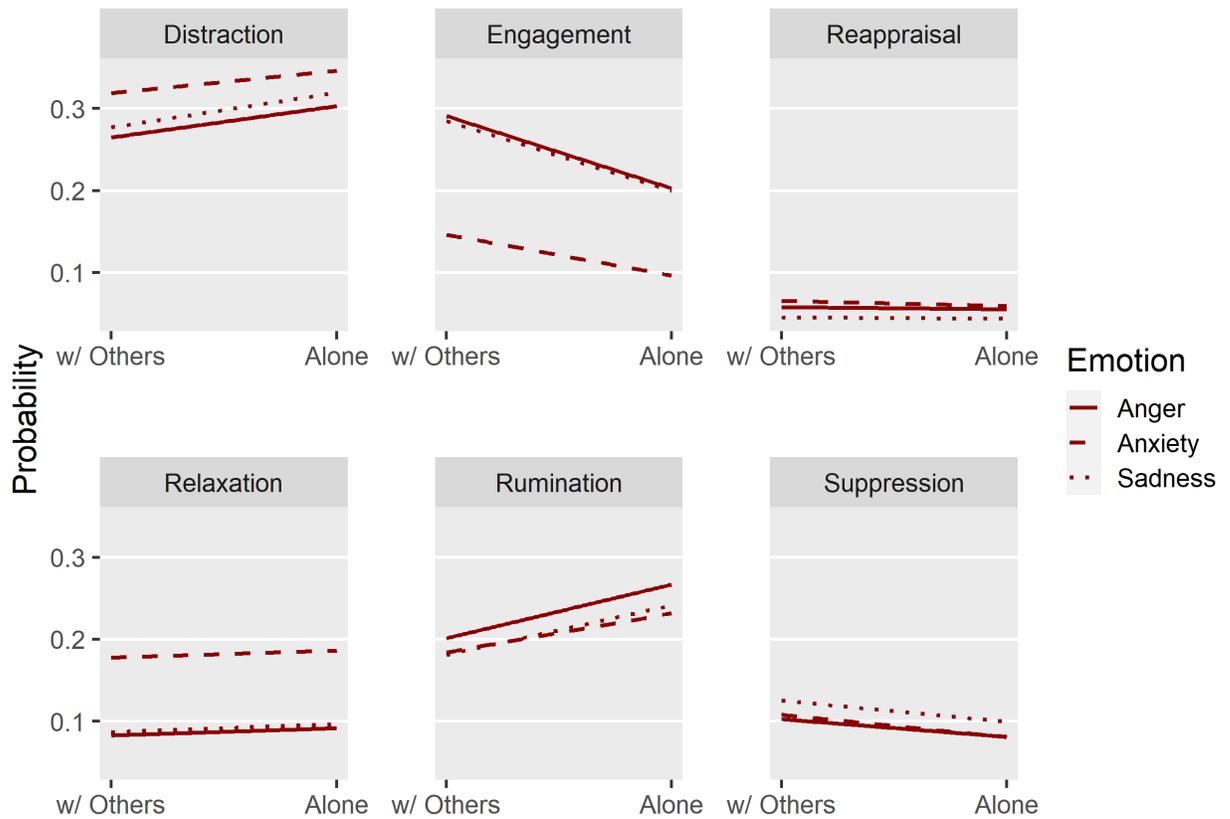
One of the difficulties of interpreting multinomial regression models is that the coefficients must be compared relative to the reference category. This is a mental step we would prefer to avoid – it would be better to just know how the probability of choosing any strategy is influenced by the covariates.²⁶ We can achieve this by visualizing the posterior predictive density.²⁷

Figure 25 shows how the probability of choosing each of the *six* strategies is influenced by both social context (Alone vs. With Others) and emotion context (Anger vs. Sadness vs. Anxiety). First, notice that the probability of selecting engagement varies as a function of social context, becoming less likely as one goes from a social to a solitary context. Nevertheless, distraction and rumination still become more likely in solitary contexts and suppression is slightly less likely in solitary contexts.

²⁶ Moreover, making inferences based solely on the coefficients can be misleading. If the reference category itself varies as a function of the covariates (as it does in this model), an estimate above or below zero may not indicate an effect (and vice versa).

²⁷ Rather confusingly, this is not the same thing as *posterior predictive simulation*. Visualizing the posterior predictive density means plotting how the *expectation* of strategy selection varies over a set of covariates.

Figure 25. Posterior predictive distributions derived from Model 3.2.

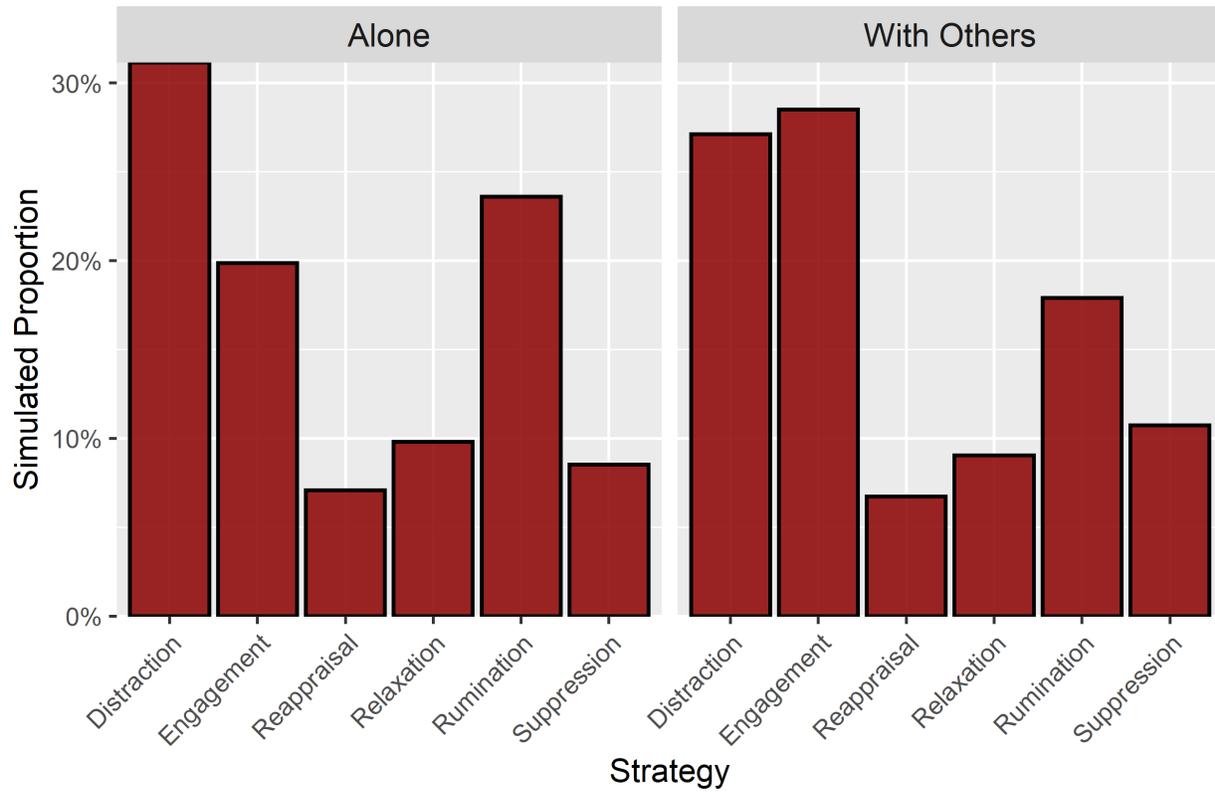


Notes: Lines depict the difference between With Others (w/ Others) and Alone in the probability of choosing each strategy. 95% credible intervals are omitted in this figure for clarity (see Appendix B for a version with credible intervals).

Simulating strategy selection.

The last thing to do with Model 3.2 is simulate strategy selection as a function of social context. We simulate 4,000 participants, where half are alone and the other half with others. Using the coefficients from Model 3.2 as probabilities, we simulate strategy selection. Simulation results are shown in Figure 26. Focusing on three strategies, we see that in the Alone condition, distraction was selected approximately 30% of the time, rumination was selected ~24% of the time, and suppression was selected ~8% of the time. In contrast, in the With Others condition, distraction was selected ~27% of the time, rumination was selected ~17% of the time, and suppression was selected ~11% of the time. We also note that reappraisal and relaxation are selected infrequently across both social conditions.

Figure 26. Posterior predictive simulation for Model 3.2 showing the simulated probability of selecting each strategy Alone vs. With Others.



Notes: Results are based on 4,000 simulated participants (2,000 Alone, 2,000 With Others).

Posterior predictive simulation for social avoidance and strategy selection.

We are also interested in the relation between trait social avoidance and strategy selection. The coefficients suggested that there may be a positive association between social avoidance and rumination and suppression, but the requirement of a reference category makes it difficult to interpret these coefficients. Therefore, we visualize the posterior distribution to examine how the *expectation* of strategy selection varies as a function of social avoidance. This is shown in Figure 27. We now see more clearly that social avoidance is positively associated with the probability of using rumination, such that at -1 standard unit score of social avoidance one is expected to use rumination 20 percent of the time, whereas at +1 standard units the expectation increases to roughly 26 percent. For suppression, the association is in the same direction but with lower magnitude (i.e., roughly 3 percent increase in probability of using suppression for a -1 to +1 standard unit shift in social avoidance).

Figure 27. Posterior predictive distributions for the relation between trait social avoidance and strategy selection.



Notes: All other variables are held at their respective sample means (social context is held at the sample proportion). Black line represents the posterior mean, red shaded region is the 95% credible interval.

Model 3.2 Summary

A lot of ground is covered in Model 3.2. We now summarize the main findings:

- Men are somewhat more likely to suppress their emotions than women. However, as with many of the gender differences in this dissertation, there is substantial variability in this estimate.
- When people are alone, they are less likely to use engagement and somewhat less likely to use suppression, but more likely to use rumination and somewhat more likely to use distraction. There are no discernible differences in the probability of using reappraisal or relaxation as a function of social context.
- People are less likely to use engagement and more likely to use relaxation when they are anxious compared to angry or sad.
- Trait social avoidance appears to be slightly associated with an increase in likelihood of choosing suppression and rumination over engagement.

Model Comparison

There were two models for the prediction of emotion regulation strategy: Model 3.1 and 3.2. Model 3.1 was an “intercept-only” and Model 3.2 included covariates (e.g., social context, social avoidance). Model comparison can tell us whether these covariates help to predict strategy selection (see Table 13). Model comparison overwhelmingly favors the more complex Model 3.2. Thus, we conclude that the covariates help to predict strategy selection.

Table 13. Cross validation summary for Models 3.1 and 3.2.

Model #	WAIC (SE)	LOO	Weight
3.1	15821.5 (96.89)	-7914.5	0
3.2	15533.2 (101.88)	-7770.7	1

Notes: Model 3.1 includes intercepts for each strategy and varying intercepts for each participant. Model 3.2 includes covariates: social context, social avoidance, time 1 affect. WAIC = Watanabe-Akaike Information Criteria; LOO = Leave-One-Out Cross Validation; Weight = a rough estimate of how much “trust” we should put in each model given its scores on WAIC, LOO, and comparisons with other models (closer to 1 = preferred model).

Models Predicting Change in Emotion

The final question to explore is whether social context and emotion regulation strategy predict change in affect from Time 1 to Time 2. Study 1 initially examined this question, but only using cross-sectional data. Study 3 used repeated assessments from the same participants, allowing us to partition the main effects from the within-participant error. However, because affect was measured as intensity on one of three discrete emotions, we are unable to directly test the deactivation effect, and instead focus more general emotion intensity from Time 1 to Time 2.

The models in this last section are varying effects regressions where intercept and slopes are allowed to vary for each participant:

$$y_i \sim \text{Normal}(\mu_i, \sigma)$$

$$\mu_i = X_i \beta_{[m,v]}$$

$$\beta_{[m,v]} \sim \Sigma_m \Omega \Sigma_m$$

$$\Sigma_m \sim \text{Exponential}(1)$$

$$\Omega \sim \text{LKJ Cholesky}(4)$$

$$\beta_m \sim \text{Normal}(0,1)$$

$$\sigma \sim \text{Exponential}(1)$$

(8)

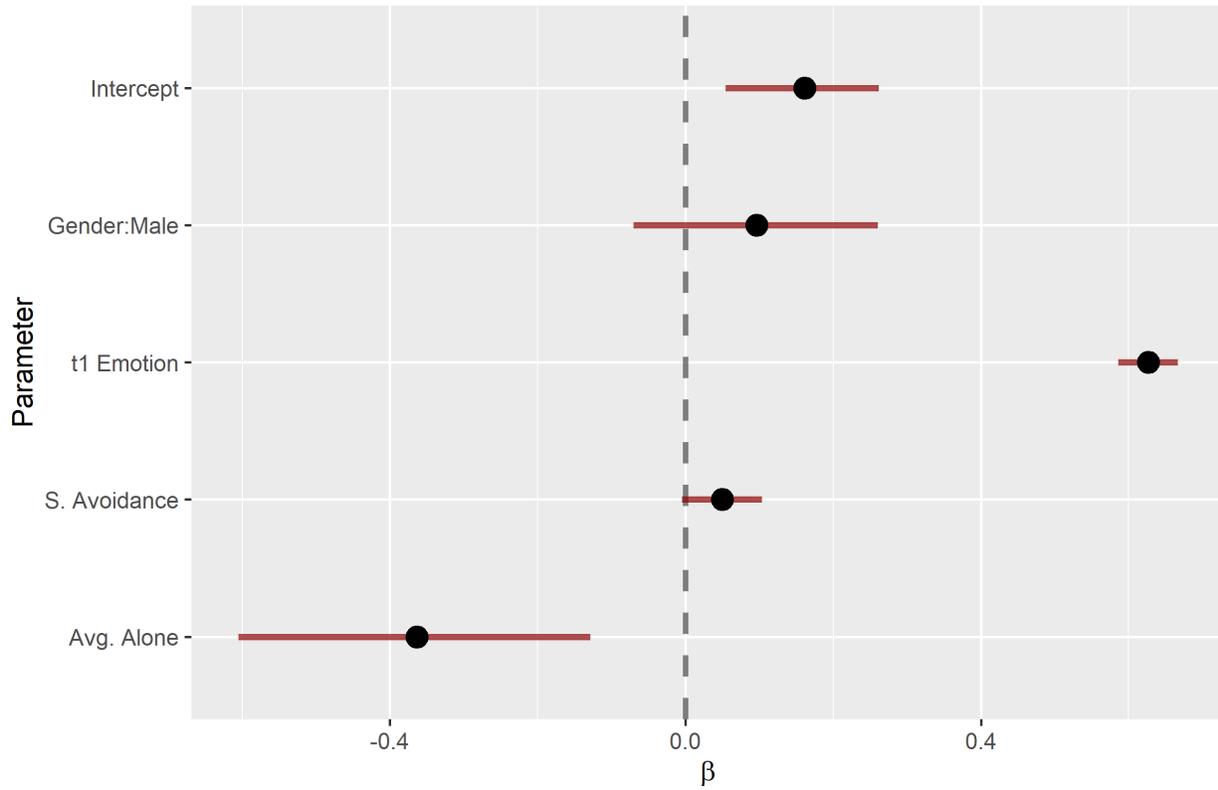
The important thing to take from Equation 8 is that the μ_i 's are determined by the matrix of covariates X_i (which is typical of any regression) but that the coefficients, $\beta_{[m,v]}$, vary by each participant. These participant-level coefficients are drawn from their own distribution, a covariance matrix which takes two priors: an Exponential prior for the variances, and an LKJ Cholesky factor correlation for the covariances.

Model 3.3: Time 1 Emotion and Trait Social Avoidance

Our baseline model 3.3 includes only gender, Time 1 emotion, trait social avoidance, and average alone as predictors of Time 2 emotion.²⁸ Coefficients for Model 3.3 are displayed in Figure 28. It is immediately obvious that Time 1 emotion intensity is a strong predictor of Time 2 intensity. Specifically, higher Time 1 intensity is associated with higher Time 2 intensity. This suggests some autoregressive stability in emotion, but does not imply that there is no change in emotion. Social avoidance does not, however, appear to be associated with Time 2 intensity. Finally, in contrast to the previous models predicting strategy selection, average alone does appear to have a negative association with Time 2 intensity. A standard unit increase in alone tendency is associated with a -0.4 standard unit reduction in Time 2 emotion intensity.

²⁸ All models also included a gender non-binary predictor term. However, because there was only one participant who self-identified as non-binary, the estimate for this parameter was incredibly uncertain, and therefore is omitted from the figures.

Figure 28. Posterior distributions for coefficients in Model 3.3.



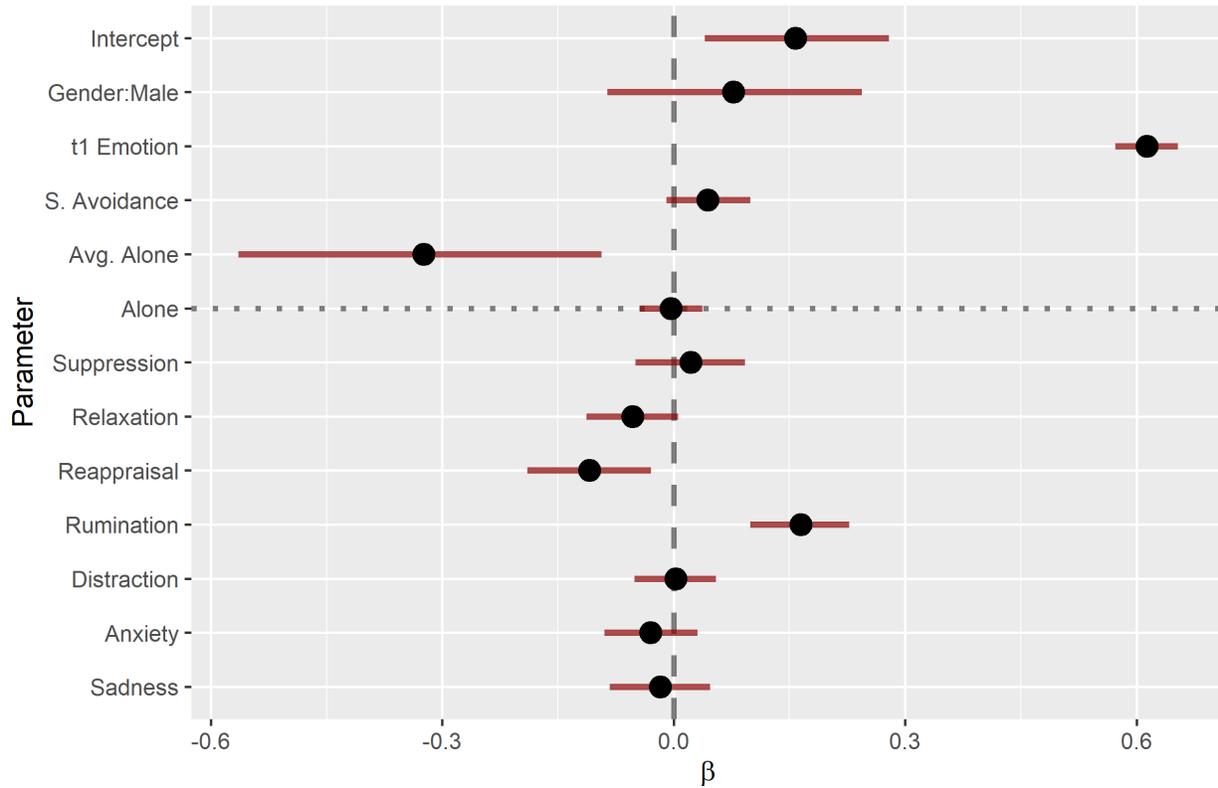
Notes: Black dots are posterior means and red lines are 95% credible intervals.

Model 3.4: Social Context, Emotion Context, and Regulation Strategies

We now include the main covariates of interest: social context (Alone vs. With Others), emotion context (Anxiety, Sadness, or Anger), and emotion regulation strategies.

Coefficients for Model 3.4 are presented in Figure 29. We note that the coefficient for alone is centered at zero, but the coefficient for average alone is still definitively negative. As for emotion regulation strategies, a trio emerge as being predictive of Time 2 emotion. Choosing reappraisal (instead of engagement) is negatively associated with Time 2 emotion intensity. Conversely, choosing rumination is associated with an increase in Time 2 emotion. The coefficients for suppression and distraction are comparatively less decisive. Emotion context may have some relation to Time 2 emotion. There is some evidence indicating that experiencing anxiety (instead of anger) is negatively associated with Time 2 emotion, but perhaps not enough evidence to claim this definitively.

Figure 29. Posterior distributions for coefficients in Model 3.4.



Notes: Parameters on or below the dotted line are new to Model 3.4 (vs. 3.3). Black dots are posterior means and red lines are 95% credible intervals.

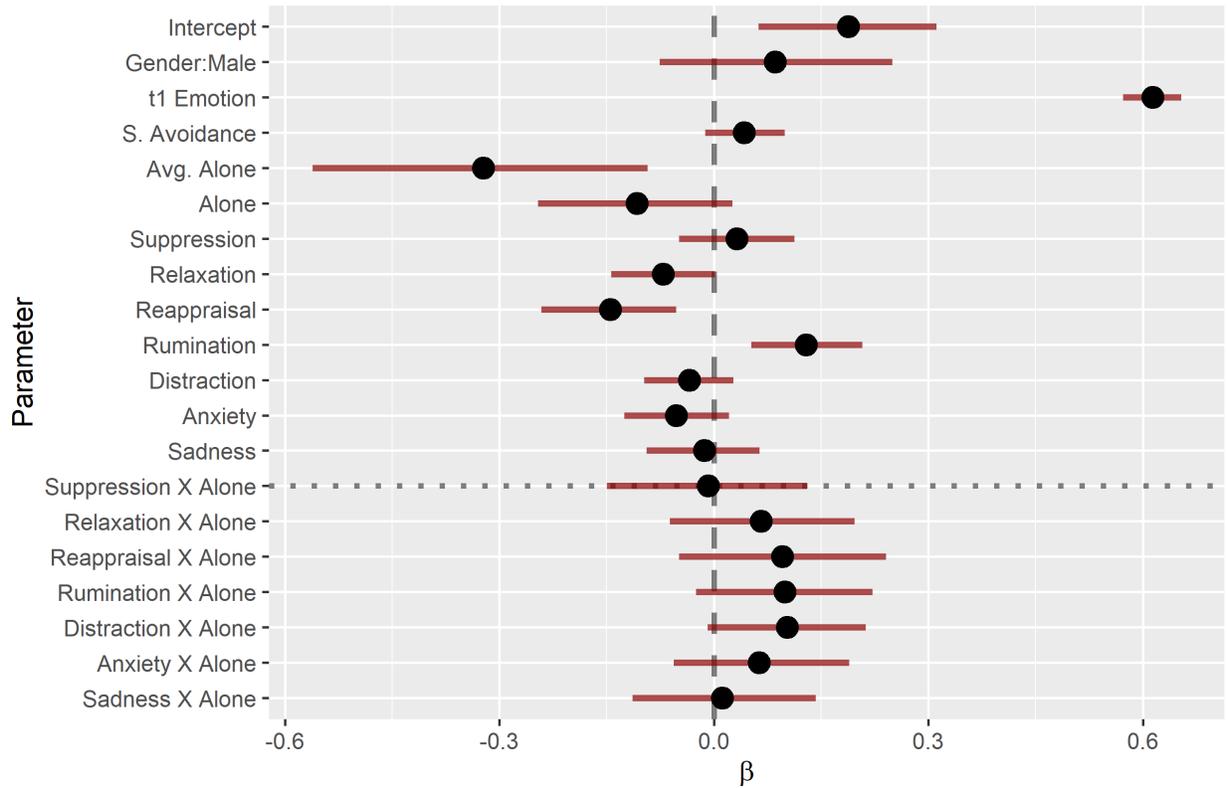
Model 3.5: Social Context and Interactions with Strategy and Emotion Context

We now include interactions between social context and strategy *and* interactions between social context and emotion context. This will help us understand whether the potential relation between solitude and change in emotion varies depending on *how* one regulates their emotions and whether one is anxious, sad, or angry.

Coefficients for Model 3.5 are presented in Figure 30. We focus our attention on the interactions as the main effects are fairly similar to the previous model. The interactions are far less certain compared to the main effects. Moreover, they are difficult to interpret because they must be compared relative to the reference category, engagement. Nevertheless, there may be some marginal evidence of a Distraction X Alone interaction, whereby choosing distraction (instead of engagement) and being alone is positively associated with Time 2 intensity. In fact, all of the strategies except suppression point in this direction (though not strongly), suggesting that the effect may be more to do with the reference category.

In contrast to the Strategy X Social Context interactions, there is no evidence of any Emotion X Social Context interactions.

Figure 30. Posterior distributions for coefficients in Model 3.5.

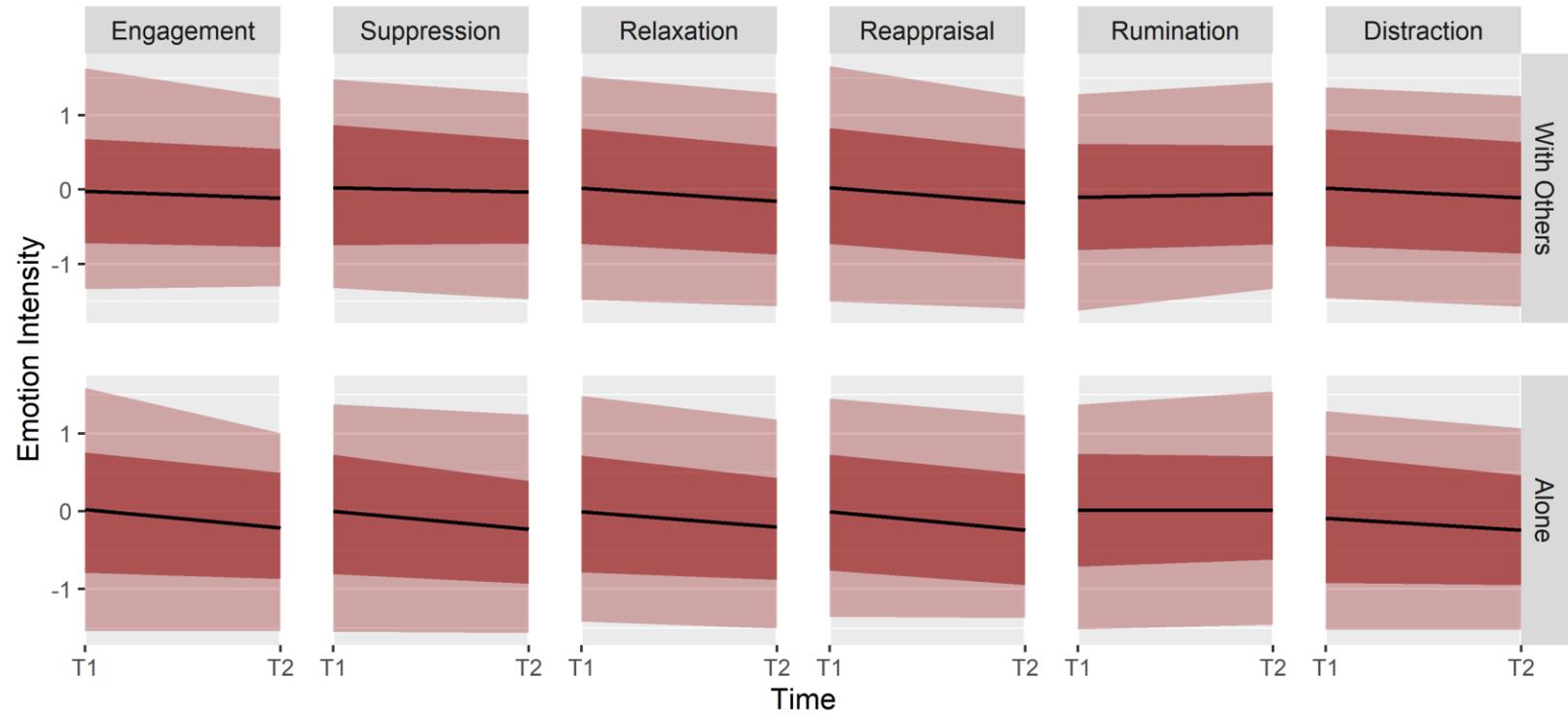


Notes: Black dots are posterior means and red lines are 95% credible intervals. Coefficients on or below the dotted line are new to Model 3.5 (vs. 3.4).

Simulating change in emotion.

We have seen before that simulating from the posterior distribution is a handy tool for understanding the world through the eyes of the model. Figure 31 shows simulated Time 1 and Time 2 emotion (averaging over emotion context) for each Strategy X Social Context combination. The line and credible interval bands capture the change from Time 1 to 2. The uncertainty we saw earlier in the model coefficients has clearly propagated to the simulation. Some combinations show a slight mean change, but overall, the uncertainty overwhelms the average and we see no obvious interactions between strategy and social context.

Figure 31. Posterior predictive simulation for Model 3.5



Notes: T1 = Time 1, T2 = Time 2. Dark red region corresponds to 68% credible interval and light red region corresponds to 95% credible interval. Results are averaged over emotion context.

Model Comparison

Finally, we perform model comparison on Models 3.3-3.5. Results are summarized in Table 14. We find that Model 3.5 performs better than the previous models in terms of WAIC and LOO. This is in spite of the fact that the novel interaction terms in Model 3.5 do not *individually* appear to predict Time 2 intensity strongly. However, together these terms add enough predictive power to the model to allow us to conclude that it is the superior model.

Table 14. Summary of model comparison for Models 3.3-5.

Model #	WAIC (SE)	LOO	Weight
3.3	8698.5 (162.65)	-4358.5	0
3.4	8596.9 (163.89)	-4312.7	0
3.5	8582.5 (163.36)	-4308.1	1

Notes: Model 3.3 includes intercept, gender, Time 1 emotion, and Social Avoidance. Model 3.4 includes Social Context and Emotion Context. Model 3.5 includes interaction terms. WAIC = Watanabe-Akaike Information Criteria; LOO = Leave-One-Out Cross Validation; Weight = a rough estimate of how much “trust” we should put in each model given its scores on WAIC, LOO, and comparisons with other models (closer to 1 = preferred model).

Study 3 Discussion

The goals of Study 3 were to understand: (1) how solitude impacts emotion regulation strategy selection; and (2) how solitude impacts change in emotion. Because this study used an experience sampling design, we were able to investigate how social context is associated with momentary emotion regulation and change in emotion, as well as compare these associations with those of trait variables, such as social avoidance and tendency to be alone. Overall, results indicated that participants were more likely to use emotion regulation strategies like rumination and distraction while alone, but solitude seems to have little impact on how effective strategies are.

Hypothesis 1: Solitude and Strategy Selection

It was hypothesized that being alone would increase the probability of using rumination, distraction, and relaxation, but decrease the probability of using suppression. The findings offered mixed support for these hypotheses.

Rumination.

First, the hypothesis that solitude would be associated with an increase in the probability of selecting rumination was supported. We would expect being alone to increase the probability of ruminating by about seven percent. As discussed earlier, this is consistent with evidence finding that people often ruminate when they are alone, particularly if they are bored (Lay et al., 2018). However, the current findings represent a novel step in this area, as they are the first to indicate that when faced with an *emotional* situation, people are at an increased risk of ruminating if they are alone.

Why would people be more likely to ruminate when alone than with others? One reason is that when people are with others it is difficult for them to ruminate. Rumination is a high

effort strategy, meaning that it takes cognitive resources (Sheppes et al., 2014). This does not mean that people generally find it challenging or taxing to ruminate – in fact, rumination happens naturally and without awareness (Wilson et al., 2019) – but that it is difficult to ruminate and perform other tasks. Being with others also requires cognitive effort, particularly if one is interacting and maintaining conversation (Wickens, 1991). Thus, it is conceivable that people may find it difficult to ruminate when they are interacting with other people because the interaction better captures their attention and cognitive resources.

Another plausible explanation is that being alone gives people more time to be with their thoughts, which makes ruminative thoughts more common. Ruminative thoughts occur naturally when one is mind-wandering or when one is bored (Shrimpton et al., 2017). Because solitude does not offer as many opportunities for social interaction, people may be less cognitively stimulated while alone and are therefore more prone to mind-wandering and rumination. This may particularly be the case when one is experiencing an emotional event as the current study examined. Negative emotional events focus our attention on the circumstances surrounding the event (Koster et al., 2005), and in the absence of social stimulation, we may tend to focus more heavily on these circumstances. Finally, it is also possible that rather than solitude making people more likely to ruminate, ruminating makes people more likely to choose to be alone.

Distraction.

Turning to distraction, the current findings were consistent with the hypothesis that people would be more likely to use distraction while alone than with others. However, the magnitude of this association was less pronounced than that for rumination – being alone increased the probability of distraction by approximately four percent, compared to seven

percent for rumination. Much of the reasoning behind the increase in rumination can be applied to explain why distraction increases in a solitary context. Social interaction is highly stimulating and thus is itself a form of distraction (Kawamichi et al., 2016), precluding the need to engage in behaviours or activities that are distracting.

Another explanation is that solitude affords more opportunities for behaviours that are distracting. Our definition of distraction was quite broad, including engaging in any kind of behaviour or activity to divert one's attention from one's emotions or thoughts related to an emotional situation. As discussed in previous sections, solitude is often portrayed as a context that affords opportunities to do a wide variety of activities (Larson, 1995). Depending on the type of activity, solitude can then be a context for distraction in a way that social situations cannot. For example, if the emotional event is tied to the social situation a person is in (e.g., argument with another person), then it is difficult for the person to engage in distraction because they must deal with the immediate demands of the social situation. In contrast, in solitude, it is conceivably easier for a person to *remove themselves* from the stressful situation.

Relaxation.

Regarding relaxation, the current study did not support the hypothesis that people would be more likely to use relaxation when alone. It made conceptual sense that solitude, which is often conceptually associated with calmness and restoration (Buchholz & Catton, 1999), would be a precursor for relaxation as an emotion regulation strategy. However, we found no evidence that relaxation is more probable in social contexts. In fact, there was a low base rate for relaxation across all contexts, perhaps making it difficult to observe differences in the probability of using relaxation. This mirrors what we found in Study 2 regarding the low prevalence of meditation and is consistent with findings from previous research, which suggest

that meditation and relaxation are overall quite rare, even in the context of solitude (Hipson, Coplan, et al., 2021).

Suppression.

The final hypothesis for strategy selection and social context was that people would be less likely to use suppression in solitary contexts compared to social contexts. We see only minimal evidence in support of this hypothesis, with the probability of suppressing decreasing by approximately two percent when people were alone. This is undoubtedly a small difference, but it is consistent with previous research (Benson et al., 2019; Daros et al., 2019; English et al., 2017). Although we did not have the ability to examine people's reasons for choosing their strategy in each situation, we expect the reason for people being somewhat more likely to use suppression in social situations has to do primarily with impression management (English et al., 2017; Goffman, 1971) – with needing to appear less “emotional” in order to save face. These previous studies argue that people are more likely to engage in an effortful strategy like suppression when they are around others because suppression serves an instrumental goal of making one seem less emotional. However, in a solitary context, there are fewer social pressures and the need for impression management is reduced (Goffman, 1971; Larson 1995), thus one would have less need to suppress their emotions, at least not for the purpose of hiding their emotion from others. Nevertheless, the current study found that social context has only a minimal impact on the likelihood of using suppression, suggesting that there may be other factors at play. For example, people may still be inclined to suppress their emotions even when they are alone if they do not want to appear to themselves as overly emotional.

Engagement.

Although not hypothesized, there was fairly strong evidence that people are more likely to use the strategy engagement in social contexts compared to solitary contexts. Engagement is a strategy that involves completely experiencing, processing, and expressing the emotion (De France & Hollenstein, 2017; Kennedy-Moore & Watson, 2001). It is curious that the probability of using this strategy should decrease so strongly (almost ten percent) in the context of solitude. Interpreting this effect is also challenging due to the comparative lack of research on engagement as an emotion regulation strategy (as we have seen, most empirical attention is on suppression and reappraisal). If we consider positive emotion events, then it makes sense that engagement would increase in social contexts because people are more likely to openly express and share their positive emotions (Boothby et al., 2014; Kennedy-Moore & Watson, 2001). However, for negative events like those in the current study, this connection is more tenuous. It is possible that the current findings for engagement have something to do with co-rumination. There is certainly conceptual overlap between co-rumination and engagement – in a social context, both involve some degree of sharing and an openness to express feelings (Rose, 2002). Therefore, it is possible that what we are seeing with engagement is actually increased tendency toward co-rumination or more broadly expressing one's feelings around others.

Putting all of this together, we conclude the following about social context and emotion regulation strategies: being alone is associated with a moderate *decrease* in the probability of using engagement, a slight *decrease* in the probability of using suppression, a moderate *increase* in the probability of using rumination, a slight *increase* in the probability of using distraction, and no changes in the probability of using either relaxation or reappraisal.

What do these findings tell us about solitude and strategy selection in general? First, the results suggest that being alone is not unanimously associated with adaptive or maladaptive strategies per se. For example, being alone increases the likelihood of both rumination (a conceptually maladaptive strategy) and distraction (a conceptually adaptive strategy) (Aldao et al., 2010; Webb et al., 2012). This is noteworthy because it goes against research suggesting that solitude is a context for negative emotions (Epley & Schroeder, 2014; Wilson et al., 2014). The current findings suggest that the picture is more complicated, as solitude increases the probability of using strategies that can help or hinder emotion regulation. Of course, we must be careful to not characterize strategies as inherently adaptive or maladaptive. On average, distraction may be adaptive and rumination maladaptive, but for future research it may be more important to consider how *flexible* people are in their strategy use (Bonanno & Burton, 2013).

A second interpretation of the broader pattern of results is that some strategies may be easier to implement in different social contexts. Thus, it is not so much that solitude makes one more likely to use a certain strategy, but that certain strategies are inherently more “social” or “solitary”. This is a subtle distinction but an important one. As an example, consider distraction: Distraction is defined as engaging in another activity to alleviate one’s emotions (Thiruchselvam et al., 2012). This means that the person has direct control over which activity they do, which, as we have mentioned, is more feasible in a solitary context when there are no social pressures and constraints (Goffman, 1971). In contrast, in a social context, a person may have to resort to other strategies like suppression because there is no socially appropriate way to use distraction.

Hypothesis 2: Does Social Avoidance Predict Suppression and Rumination?

The next hypothesis was that those higher in trait social avoidance would be more likely to use suppression and rumination. The current findings mostly supported this hypothesis. Those higher in trait social avoidance were more likely to use rumination and somewhat more likely to use suppression. Overall, these findings are consistent with previous research linking social avoidance and social anxiety (of which social avoidance is a marker) to an increased tendency to ruminate and suppress one's emotions (Dickson et al., 2012; Kivity & Huppert, 2019; Nepon et al., 2011). These associations are most easily explained by the co-occurrence of social avoidance with other socio-emotional difficulties and psychological disorders, such as anxiety and depression, which are associated with maladaptive emotion regulation strategies (Aldao et al., 2010; Dickson et al., 2012; Webb et al., 2012).

However, it is possible that there is something unique about social avoidance in relation to rumination and suppression. If we consider emotional situations that take place within a social context (which if we are honest would be most emotional events), then a socially avoidant person is confronted with twice the number of challenges: they must deal with the anxiety and stress of the social aspects of the event (e.g., deciding what to say) on top of the problems inherent in the emotional event itself (e.g., dealing with what is causing the emotion, deciding how to cope with the problem). Faced with more intense emotions, they would be more likely to choose strategies like suppression and rumination that have previously been found to occur more often under highly stressful circumstances (Sheppes et al., 2009; Sheppes & Meiran, 2008). Moreover, those who are socially avoidant are more likely to experience feelings of self-consciousness, which would prompt them to use a strategy like suppression to hide their feelings from others (Monfries & Kafer, 1994). Although these two factors, stress

associated with the event and feelings of self-consciousness, help to explain why socially anxious individuals are more likely to use suppression and rumination, it is unlikely that these strategies are particularly helpful for dealing with these emotions (Aldao et al., 2010).

Hypothesis 3: Emotion Context and Strategy Selection

A third set of hypotheses were concerned with how strategy selection varies as a function of which emotion the person is experiencing – otherwise referred to as the *emotion context*. Recall that three emotion contexts were examined in this study: anger, sadness, and anxiety. Specifically, it was hypothesized that people would be more likely to use reappraisal when sad or anxious. Contrary to our hypothesis, reappraisal appeared to occur at the same frequency regardless of which emotion the person reported. This contrasts with previous research. Specifically, Benson et al. (2019) found that people were more likely to use reappraisal (as opposed to suppression) when sad, and Rivers et al. (2007) reported that reappraisal was more effective in dealing with sadness compared to anger (although this does not necessarily mean that reappraisal was used more often). It is possible that the low base rate for reappraisal in the current study made it difficult to observe meaningful differences in emotion context. Benson et al. (2019) were the only study to report increased *frequency* of reappraisal when people experienced sadness, but they only compared reappraisal to suppression. Perhaps by including more strategies, the difference becomes much less noticeable.

Although not hypothesized, we found that people were roughly ten percent more likely to use relaxation and ten percent less likely to use engagement when anxious. The link with relaxation makes conceptual sense. Anxiety involves elevated heart rate, blood pressure, etc. which can be alleviated by performing breathing techniques and calming oneself (Jerath et al., 2015). In contrast, the link with engagement is less obvious. Perhaps people view anxiety as a

more unpleasant emotion from an experiential standpoint and are therefore less likely to want to engage with and experience the emotion. There is evidence to suggest that people feel a sense of entitlement to emotions like anger and sadness (Witte et al., 2002), whereas anxiety may be viewed as inconvenient or troublesome. This is also consistent with the view that anger and sadness serve clear functions (anger signals a blocked goal; sadness signals loss), whereas anxiety can occur in the absence of actual threat (unlike fear) (Frijda & Mesquita, 1994).

Taken together, we conclude the following about social context and emotion regulation strategy selection. First, is that being alone increases the probability of a person using distraction and rumination and it decreases the probability of using engagement and (to a lesser extent) suppression. Second, people higher in trait social avoidance are more likely to use rumination and suppression – both of which previously been identified as “maladaptive” emotion regulation strategies (e.g., Aldao et al., 2010). Third, contrary to hypotheses, people were more likely to use relaxation and less likely to use engagement when anxious, but otherwise there were no discernible differences among the three emotions. The next set of hypotheses deals with change in emotion as a function of social context and emotion regulation strategies.

Hypothesis 4: Interrogating the Deactivation Effect Again

We return again to the deactivation effect of solitude – that being alone will be associated with a reduction in arousal/emotion intensity. Evidence across Study 3 was largely unresponsive of the deactivation effect. There was no meaningful reduction in emotion intensity among those who were alone compared to those who were with others. We note that in the final model, being alone appeared to be marginally negatively associated with Time 2 emotion intensity, but this estimate is highly uncertain and there is a portion of the 95 percent credible interval that exceeds

zero. Thus, we conclude that there is no solid evidence in support of the deactivation in this study.

These findings are not consistent with the hypothesis and results from Study 1. The most likely reasons for the discrepancy are differences in measurement across the two studies. Study 1 measured arousal whereas Study 3 measured emotion intensity. Emotion intensity is a proxy of arousal, but it differs in the following respects. First, arousal is tied to the subjective experience of physiological activity, whereas intensity is vaguer, extending beyond physiological activation to include amount of cognitive processing, severity of the event and its consequences, and other emotion qualia (Barrett et al., 2004). Indeed, there are scenarios in which arousal could conceivably diverge quite strongly from emotion intensity. One such scenario would be a depressive mood, which can be emotionally intense but is theorized to be at the low end of arousal spectrum (Russell & Barrett, 1999; Russell & Mehrabian, 1977). Thus, it is possible that if the current study had used a measure of arousal as opposed to emotion intensity, there would be stronger evidence of a deactivation effect.

Another relevant difference between the two studies is that Study 1 used a single time point assessment (albeit with questions framed in such a way to assess change over time), whereas Study 3 used an experience sampling paradigm. In both cases, participants were asked to reflect on emotions in past, but for Study 3 the time interval was only one hour in the past, whereas for Study 1 it was 24 hours. It is possible that this could have led to a discrepancy in the findings between the two studies as participants' responses in Study 3 would be less influenced by recall bias. The change in affect reported in Study 1 may actually be the result of implicit beliefs about how being alone changes our emotions (Tamir et al., 2009). In other words, people may unconsciously expect to experience a reduction in arousal when they are alone, which in

turn, would influence how they responded in the questions in Study 1. In Study 3, however, they would be less prone to recall bias and presumably their responses would be less influenced by implicit beliefs (Ebner-Priemer et al., 2006). This interpretation remains speculative as there is no empirical evidence to suggest that people implicitly believe solitude is deactivating.

Hypothesis 5: Social Context and Strategy Interactions

It was further hypothesized that social context and emotion regulation strategies would interact to predict change in emotion intensity. Specifically, it was expected that those who were alone and ruminating would experience a greater increase (or less of a decrease) in emotion intensity compared to those who were with others and ruminating (Rose et al., 2002). It was also hypothesized that the use of distraction while alone would result in a stronger decrease in emotion intensity compared to those who are with others and use distraction. Overall, evidence was inconclusive for these hypotheses. Some of the estimates only barely included zero within the credible interval, but the amount of uncertainty in the estimate is such that one should be skeptical about the existence of a true interaction. Posterior predictive simulation showed that there could be very slight interaction effects, but they are far from compelling. Therefore, we conclude that there are no interactions among social context and strategies or, at least, if there are interactions, then they are subtle and unlikely to be noticeable in a real-world setting.

This null finding shows a similar pattern to that of Study 1. Namely, there was a lack of convincing evidence of social context by strategy interactions in Study 1. Moreover, previous research is predictably mixed concerning these interactions (e.g., DeLongis & Holtzman, 2005; Stone et al., 2019). It is interesting to note that the current literature on emotion regulation is moving away from the deterministic *strategy X context = change in emotion* standpoint and instead embracing emotion regulation flexibility (Aldao & Nolen-Hoeksema, 2012; Bonanno &

Burton, 2013; Pruessner et al., 2020). From this perspective, it matters less which strategy one uses, but whether they are able to use a variety of strategies in such a way that is catered to the specific situation. Under this framework, we would not expect to find social context by strategy interactions because the effectiveness of strategy would vary by infinitely more factors than the social context (more on this in the General Discussion).

Study 3 Limitations and Conclusion

Despite the strengths of this study, which include the use of high frequency momentary assessments on a reasonable sample of young adults, there are some limitations that should be addressed in future studies. One of these is the use of a single strategy approach (i.e., participants only indicated which strategy they recalled using the most) where it may make more sense to assess the extent to which people used several strategies at a given time point. This is more consistent with the notion of emotion regulation flexibility where people can be engaged in multiple strategies (Bonanno & Burton, 2013; Ford et al., 2019). This would allow us to examine whether certain strategy *combinations* are more common in a solitary context. Perhaps while alone people use both distraction and rumination, or they predominately use one of these strategies. Further, an emotion regulation flexibility approach would enable us to examine how strategy combinations used while alone are associated with how our emotions change over time.

Another limitation has to do with experience sampling methodology. Our experience sampling paradigm prompted participants at fixed intervals during the day (morning, afternoon, and evening), but there are notable advantages of using an event-contingent approach (Wheeler & Reis, 1991). One advantage has to do with recall bias. In the time between intervals participants may have forgotten or misattributed their feelings and strategy selection, but with

event-contingent sampling, this window would be reduced because participants would be answering questions immediately following the event. Another related advantage is that subsequent events may change how a participant thinks about the event. For example, if an argument is eventually resolved, then the people involved would probably recall the emotional event quite differently than if the argument were left unresolved. Thus, depending on when the prompt occurs along this timeline, the participant may answer questions about their emotions quite differently. Of course, event-contingent sampling poses its own methodological challenges, most notably that participants self-initiate the sampling, which can be a lot to expect of people when they are facing stressful situations.

General Discussion

People lead active social lives. Yet, we often fail to appreciate that much of our time is spent away from other people, in solitude. This realization evokes important questions about whether being alone is good or bad: is some amount of solitude a good thing, or do we always end up feeling less happy when we are alone? These questions have become all the more relevant now. At the time of the writing of this dissertation, the world is at grips with a global pandemic and most governments have responded by restricting social gatherings and encouraging the public to physically distance themselves from others. As a result, people are spending more time alone (Ellis, Dumas, & Forbes, 2020; López-Bueno et al., 2020).²⁹ Therefore, it behooves us to understand how solitude impacts not only our current emotional state, but how we deal with difficult emotions.

²⁹ At the time of writing, research on the effects of COVID-19 on people's daily routines, health, and well-being are still highly preliminary. Moreover, because of the everchanging nature of the pandemic, restrictions such as lock downs fluctuate over time, making it increasingly difficult to gauge the immediate and long-term effects of COVID-19 related isolation.

The goal of this dissertation was to understand how solitude impacts change in emotions over time. More specifically, this dissertation involved developing and evaluating a *Contextual Model of Solitude and Emotion*, which takes into account the roles of series of both person- and situation-level factors (see Figure 3). At the heart of this model is the idea that emotion changes over time, but our social context, emotion regulation strategies, activities, and personality can influence *how* emotion changes over time. Over a series of studies, we explored each of these factors and their interactions to arrive at a deeper understanding of the complex linkages between our social lives and our emotional lives. We now consider the broader implications of these findings with respect to theory, as well as some practical guidelines for mental health and well-being. It is also worth noting that this dissertation is the first in the study of solitude to use a Bayesian statistical paradigm instead of a Frequentist paradigm. Although it was outside of the scope to compare these two approaches, a brief discussion of the unique implications of choosing a Bayesian paradigm is provided, as well as some recommendations for adopting it.

Solitude, Emotion, and Emotion Regulation

Emotions are complex, emergent processes. This means that an emotion is the product of interactions among different systems, such as cognitive appraisal, physiological activity, expressivity, and subjective feeling (Scherer, 2009). Consequently, it is nearly impossible to empirically investigate emotion in a holistic sense, and thus this dissertation was largely concerned with subjective feeling of emotion. Moreover, as we have seen, the study of emotions should not be limited to *prototypical emotions* (e.g., fear, anger, and joy), but should include affect more broadly (i.e., how one feels at any given time) (Fogel et al., 1992; Hollenstein, 2015; Kuppens, Oravecz, et al., 2010). According to this view of emotions, subjective feeling can be measured along two dimensions: valence and arousal (Russell & Mehrabian, 1977; Russell,

1990; 2003). However, we can also measure more specific, discrete states, such as anger, sadness, and anxiety. As discussed earlier, both frameworks speak to different components of the emotion process, so there is no reason to favour any one in particular. Emotion regulation was conceptualized as the deliberate or unconscious process of changing one's current state (usually a negative state) to a more positive state (usually a baseline state) (Gross, 2015). In this dissertation, the focus was on which emotion regulation strategies people tend to use and how effective they are in bringing one's affective state back to its baseline.

Under this paradigm, the first goal of this dissertation was to examine the role of solitude (or, more broadly, social context) in how emotion changes over time following an emotional event. This included several attempts to empirically replicate previous research pertaining to the *deactivation effect*, which posits that spending time alone reduces high arousal positive and high arousal negative emotions (Nguyen et al., 2018). However, across the three studies, evidence for the deactivation effect was mixed. In the context of negative events, there is some support for the idea that being alone is associated with a greater reduction in arousal compared to being with others; however, the same was not found to be true in the context of positive events. Moreover, the finding only emerged in one of the studies and, importantly, was not found when an experience sampling paradigm was used. This casts some doubt on the robustness of the deactivation effect, suggesting that it is highly dependent on the precise measure of affect, or is influenced by factors such as recall bias (see Study 1 Discussion for a more detailed discussion).

A prevailing narrative in the solitude literature is that time alone can be *restorative* – relaxing, calming, stress-reducing (Buchholz & Catton, 1999; Korpela et al., 2001). The deactivation effect has been used to support this claim (Coplan, Hipson, et al., 2019; Nguyen et al., 2018). Some studies go as far as to equate deactivation with restoration (e.g., Love &

Zelikowsky, 2020), where, in fact, deactivation is broader than restoration, as it includes low arousal *negative* emotions, such as gloominess, despondency, and boredom (Russell & Mehrabian, 1977). Thus, even if we take the deactivation effect to be robust, it is not sufficient as evidence for solitude being restorative.³⁰

Solitude is only likely to be restorative if one is in an environment and frame of mind that is conducive to restoration. This may seem tautological, but it speaks to the idea that the link between solitude and emotion is context dependent. Solitary experiences are heterogeneous, so there is little reason to expect that being alone would reliably lead to restoration. For instance, Lay et al. (2018) demonstrated that solitary experiences can be broadly categorized as *negative* (involving high negative affect and effortful thought) or *positive* (involving minimal negative affect and minimal effortful thought). It is probably the positive solitary experiences that people think about when they argue that solitude is restorative, whereas the negative solitary experiences, those that involve feelings of loneliness, isolation, and boredom, are not reflective of *true* experiences of solitude (Galanaki, 2004).

The idea of *true* or *authentic* solitude has been suggested by some researchers (e.g., Averill & Sundararajan, 2014). According to this view, authentic solitude: (1) is intrinsically motivated; (2) is a creative experience that requires mental effort or awareness; and (3) requires freedom from some social pressures and constraints. Under this more restrictive definition of solitude, there would likely be more favourable evidence for deactivation and even restoration. There are meditative and spiritual components unique to authentic solitude, which are plausibly conducive to feelings of calmness, connectedness, and peace (Averill & Sundararajan, 2014; Long et al., 2003).

³⁰ It is worth noting that Nguyen et al. (2018) make this point in their paper, despite the fact that it is often cited as evidence of solitude as restoration.

There is also some recent evidence of this idea in how language is used to describe aspects of being alone. For example, A comparison of tweets containing the word *solitude* versus the words *lonely/loneliness* revealed that these words are used in different emotional contexts (Hipson, Kiritchenko, et al., 2020). The word *solitude* more often occurs in tweets containing high valence, low arousal, and high dominance words.³¹ Thus, the notion that solitude is restorative may only apply in situations in which solitude is authentic. Perhaps this is reason enough for researchers to reject the idea that solitude is the same as being alone, and instead conceptualize solitude as a more complex social and cognitive construct.

The second main goal of this dissertation was to examine the link between solitude and emotion regulation strategies. Our *Contextual Model of Solitude and Emotion* posits that solitude is a context for different emotion regulation strategies to play out. In support of this model, it was found that being alone not only increased the likelihood of using distraction and rumination, but also decreased the likelihood of using suppression and engagement. Thus, different social contexts appear to make for different emotion regulation goals. In a social context, a person is more likely to adhere to *instrumental goals*, such as appearing cool and calm in a stressful situation, whereas in a solitary context, they have more freedom to adopt *hedonic goals*, such as playing a video game to distract themselves (English et al., 2017; Sheppes & Meiran, 2008). However, the current findings do not indicate that these strategies are any more *effective* in a solitary versus a social context.³² Thus, solitude may be a context for different emotion regulation strategies, but the implementation and efficacy of these strategies remains the same across various social contexts.

³¹ Dominance is a third dimension of affect corresponding to how ‘in control’ versus ‘out of control’ a person feels. In the context of the tweets study, more dominance was interpreted as reflecting intrinsic motivation.

³² There was slight evidence that distraction is more effective when used alone, but there is too much uncertainty to give this finding any credibility in absence of corroborating research.

What does this mean for how people cope with difficult emotions? First, we cannot say whether solitude is good or bad just because it permits the use of certain strategies. As previously discussed, the evidence only suggests that solitude is associated with strategies like distraction and does not go so far as to suggest that putting oneself in a solitary context causes one to use more distraction. For instance, one might use distraction or rumination in solitude because being alone affords fewer opportunities to use other strategies (including those not examined in Study 3, like social support). Alternatively, one might conceivably seek out solitude *in order to* use strategies like distraction. Moreover, even if there is a causal relation among solitude and emotion regulation strategies, the literature on emotion regulation and well-being would suggest that the more maladaptive strategies like rumination would cancel out the increased probability of the more adaptive strategies like distraction (Aldao et al., 2010; Webb et al., 2012). In other words, solitude seems to increase the likelihood of using both distraction *and* rumination, meaning that there is an overall net zero gain in emotion regulation effectiveness.

To summarize, this dissertation provides some evidence that solitude is associated with a greater reduction in arousal following a negative event. However, the evidence appears to more strongly suggest that solitude is implicated in how one chooses to regulate their emotions. Thus, it seems unlikely that solitude itself is an effective emotion regulation strategy (only limited evidence of deactivation, which is not inherently good or bad for one's well-being) and, although it increases the likelihood of some strategies, these strategies are a mix of more adaptive and more maladaptive approaches. Taken together, social context is important in how people experience and regulate emotions, but it is unclear whether solitude is the answer for coping with these emotions.

Do Solitary Activities Matter?

Most research on solitude has focused on *time* spent alone (e.g., number of hours spent in solitude). However, as we have seen, solitude is heterogenous. People can be alone and doing any number of different activities, and it is plausible that solitary activities may impact emotions differently (Hipson, Coplan, et al., 2021). This dissertation examined solitary activities in Study 2, which unfortunately only used a single time point assessment of activities and time alone. There was minimal evidence in support of the differential impact of solitary activities on affect. This begs the question of whether the effect of solitude really depends on *how* one spends their time alone or it is only important to consider *how much* time one spends alone.

The main challenge in assessing solitary activities is deciding at what level of granularity to categorize different activities. At the least granular level is a functional categorization scheme. In a functional scheme, activities are grouped together if they share the same motivational underpinnings. For instance, some researchers have grouped together activities on the basis that they are likely to be intrinsically motivated (e.g., creative pursuits) (Coplan, Hipson, et al., 2021). Similarly, other researchers have categorized certain activities as *leisure*, representing any activity that is done for enjoyment and pleasure (Kleiber et al., 1986). The advantage that such categorization schemes have is that it is easier to statistically compare different types of activities. However, the disadvantage is that they assume that the motivational underpinnings for certain activities are constant. This assumption is unlikely to hold in reality. For example, creative pursuits are assumed to fall under the category of intrinsically motivated activities, but other motivations for doing these activities could include professional or occupational, satisfying another person, as well as satisfying one's own expectations. Because of these limitations, this dissertation used a granular categorization scheme of solitary activities,

focusing more on the type of behaviour instead of its purported underlying motivation (e.g., Hofferth & Sandberg, 2001). This scheme has far fewer assumptions compared to the functional one, but it is statistically more difficult to compare the wide variety of activity types. This could help to explain why this dissertation found little evidence that solitary activities are differentially associated with affect.

Thus, we may need to rethink how we measure and conceptualize the potential impact of solitary activities. Writing about the developmental significance of solitude, Larson (1990; 1997) proposed that solitude could afford benefits for adolescents and emerging adults because it provides opportunities for self-discovery, independence, and creativity (see also Coplan, Ooi et al., 2019). These are undoubtedly important developmental milestones but is hard to see the immediate connection between concepts like self-discovery and affect. Perhaps solitude affords benefits, but these benefits do not translate directly to our current emotional state. This is the difference between *hedonia* and *eudaemonia*. Hedonia is the experience of pleasure, eudaemonia is the experience of satisfaction with life – a deeper feeling that one’s life has meaning (Deci & Ryan, 2008). Solitude may not be inherently hedonic, but perhaps some amount of solitude is eudaemonic (this point is also made by Averill & Sundararajan, 2014, in their treatise on authentic solitude).

We could extend this thinking to solitary activities. Spending one’s time alone doing hobbies, meditating, or being in nature could over time lead to a greater sense of eudaemonia (e.g., connection with nature, self-discovery, spiritual meaning), whereas spending that time watching videos on the internet may only offer a fleeting sense of hedonia. Taken together, research on solitary activities is only just getting started, and more evidence is needed (especially

evidence gained through experience sampling) before we can conclude if and how solitary activities are relevant to our emotional experience of time alone.

Integrating Findings on Extraversion, Preference for Solitude, and Social Avoidance

There is a wealth of previous evidence indicating that personality is a major factor in both how much time we spend alone and how we experience that time alone (Coplan, Hipson, et al., 2019; Fatfouta, 2017; Teppers et al., 2013; Wang et al., 2013). What has been somewhat less clear is how specific personality traits are related to the frequency and experience of solitude. This dissertation explored personality as a *person-level* factor in the larger *Contextual Model of Solitude and Emotion*. Across three studies, three related but conceptually distinct personality traits were examined: extraversion, preference for solitude, and social avoidance. We now reflect on what the current findings tell us about each of these traits and attempt to integrate them to form a larger understanding of motivations, personality, and emotions related to time spent alone.

The current literature on solitude emphasizes the role of motivation as a distinguishing feature among different attitudes and tendencies toward spending time alone (Coplan et al., 2013; Goossens, 2014; Leary et al., 2003). Preference for solitude (or *unsociability* as it is often called in the developmental literature), is a non-fearful tendency to seek solitude because one simply enjoys being alone. In stark contrast, social avoidance is a tendency to seek solitude out of a desire to avoid people and to alleviate social anxiety (Asendorpf, 1992; Brown et al., 2007; Coplan et al., 2004). Extraversion is a broader construct that pertains not only to motivation (e.g., sensation-seeking), but also to behavioural tendencies (e.g., talkative) and physiological differences (e.g., behavioural activation system vs. behavioural inhibition system) (Carver &

White, 1994). On top of these are a multitude of other related terms not addressed in this dissertation, including social withdrawal, shyness, and social anxiety.

In relation to solitude and emotion dynamics, extraversion specifically seems to predict whether one will be alone following an emotional event. Yet, surprisingly, it does not appear to influence how one's emotions change over time while they are alone, which contrasts with earlier theory (Geen, 1984). Further complicating matters, extraversion is intimately linked with affect itself (extraverts tend to be happier and prefer higher arousal states; Hemenover, 2003). This makes it impossible to assess the role of extraversion in change in emotion in the absence of repeated-measures data. What we do know from experience sampling studies is that extraverts experience increases in positive affect more so *because* they tend to spend more time interacting with others and less because they are inherently happier (Lucas et al., 2008; Srivastava et al., 2009). Thus, it seems that extraversion influences affect indirectly through the behaviours that are related to extraversion. Future laboratory experiments are key to improving our understanding how extraversion and social behaviours interact to influence change in emotion over time.

In contrast to extraversion which seems only to predict social interaction, preference for solitude may influence people's experiences of time spent alone. Across the two studies that measured preference for solitude, the findings were mixed. Study 1, which explored change in affect during emotional events, found no evidence of a moderation effect with preference for solitude. Study 2, however, which focused on overall time spent alone and affect, found reasonable evidence that among people who prefer solitude, there is a stronger relation between time alone and positive affect. The latter finding is certainly more consistent with our conceptual

understanding of preference for solitude, and it converges with previous research (Lay et al., 2018).

Nevertheless, the evidence is far from convincing, which leads us to question whether *preferring* solitude is enough to make it an enjoyable experience. People may want to spend time alone, but actually find the experience less pleasant than expected. Previous research on affective forecasting suggests that people erroneously expect that time alone will be more pleasant than time with a stranger (Epley & Schroeder, 2014; Wilson & Gilbert, 2003). As mentioned earlier, this is even true among introverts (Zelenski et al., 2013), so there is reason to expect that the same may occur for those who prefer solitude. It is also true that preference for solitude is strongly correlated with other measures of social withdrawal (e.g., shyness, social avoidance), as well as outcomes related to social withdrawal (e.g., loneliness, depression, and anxiety) (Endo et al., 2017; Wang et al., 2013; Waskowic & Cramer, 1999). Although controlling for loneliness and social anxiety has in some cases found to attenuate or nullify these correlations (see Goossens, 2014 for a review), there remains conceptual overlap among these different motivations for solitude. It is not hard to imagine situations in which a benign preference for solitude devolves into something more sinister. Thus, preference for solitude on its own is probably not cause for concern, but it also does not likely occur in isolation.

The third and final personality trait explored in this study was social avoidance: the tendency to avoid social interaction out of disinterest and/or social anxiety (Brown et al., 2007). In contrast to introversion and preference for solitude, which are not viewed as inherently problematic, social avoidance is a clear marker of psychological maladjustment (Ottenbreit & Dobson, 2004). Although this dissertation did not explore the clinical implications of social avoidance, Study 3 revealed that it is positively associated with the use of rumination as an

emotion regulation strategy. Previous studies have consistently linked rumination with psychological maladjustment (Aldao et al., 2010; Nolen-Hoeksema et al., 2008), which in turn, suggests that rumination may be a mediating factor linking social avoidance to depression and anxiety. Moreover, the current findings indicate that the link with rumination may be unique to social avoidance in comparison to extraversion and preference for solitude. Indeed, although all these traits were not examined in the same study, evidence from Study 1 shows negligible correlations among rumination and extraversion ($r = -.08$) as well as rumination and preference for solitude ($r = .04$).

Taken together, several broad conclusions can be offered with respect to how personality is related to solitude and emotions. First, Extraversion is a broad trait that is predictive of time spent alone and baseline affect, but does not appear to influence how affect changes over time when one is alone. Second, preference for solitude is a more specific inclination toward spending time alone and may moderate the relation between time alone and affect, such that among those who prefer solitude, spending more time alone is related to more positive affect. However, preference for solitude does not appear to influence change in affect following an emotional event. Finally, social avoidance is predictive of rumination as an emotion regulation strategy, which may help to explain the linkages between social avoidance and socio-emotional difficulties, such as depression and anxiety. Notwithstanding these conclusions, there is a dire need for further validation, particularly regarding the relation between preference and solitude and change in emotion, which could not be examined with sufficient rigour in this dissertation.

Putting everything together, this dissertation supports some components of the *Contextual Model of Solitude and Emotion*. At the center of the model, is the idea that solitude influences the *experience* of emotion (i.e., change in emotion over time) and the *regulation* of

emotion (i.e., which emotion regulation strategy one uses). Specifically, solitude was moderately associated with a greater reduction in arousal, and social interaction was moderately associated with an increase in valence. Additionally, different personality traits continuously interact with these associations. Extraversion predicts whether one will resort to a social or solitary context, preference for solitude may predict whether one enjoys being in a solitary context, and social avoidance predicts which strategies one will use. Finally, the chosen strategy may also impact how one's emotions change over time.

Reflections on a Bayesian Paradigm

A relatively novel aspect of this dissertation, with respect to the psychological sciences, was the use of a Bayesian paradigm. It is worth reflecting on this approach, considering how the process differed from that of the traditional Frequentist approach and contemplating how the current approach could have been improved.

An immediate result of performing Bayesian statistics is the lack of p -values as a means of rejecting a null hypothesis. Given the current rancorous climate surrounding p -values in wake of the Replication Crisis (see Amrhein et al., 2019), a lack thereof may be considered an asset. However, this is a narrow reading of the differences between Bayesian and Frequentist statistics. Bayesians have their own way of deciding to reject or support a hypothesis (although it is not usually in the context of rejecting a null hypothesis). There are *Bayes factors*, which have a similar flavour to p -values and come with interval guidelines similar to effect sizes (e.g., a Bayes factor between 3-10 is considered moderate evidence) (Lee & Wagenmakers, 2014).

However, with model comparison approaches like cross validation, Bayes factors are somewhat unnecessary (see McElreath, 2020 for more on this). This dissertation did not use Bayes factors for this reason. Hypotheses concerning parameter values (e.g., whether a slope is

likely to be above or below zero) were performed by examining the 95 percent density of the posterior distribution. This sounds similar to null hypothesis testing – and it is in the sense that one eventually has to decide whether to accept or reject a hypothesis – but it provides a bit more flexibility because one can say with 95 percent confidence that the parameter value lives within that region. Moreover, one is not restricted to testing a null hypothesis (a hypothesis that is often unreasonable to begin with). Indeed, one could simply compare competing hypotheses from the outset, or see how much new data adds to prior knowledge. In retrospect, this could have been an ideal strategy for exploring whether solitude is best considered as an emotion regulation strategy or a context for emotion regulation strategies. Nevertheless, the *contextual model* incorporated both these linkages.

Taken together, Bayesian statistics is a powerful tool for doing inference. The main advantage is in how it incorporates prior knowledge (e.g., expert knowledge or regularization) and in how the results are interpreted directly in the language of probability. In the psychological sciences, Bayesian statistics could be particularly helpful in testing complex models that house many assumptions. In these cases, it would be sensible to use priors because as the number of proposed variables in a model increases it quickly becomes unfeasible to measure all of their interrelations. A researcher could use priors informed by previous research on some of the associations and then use data to estimate those that are of particular interest. Such an approach could even offer a principled way of integrating theoretical models that are traditionally used in disparate fields of psychology or perhaps across scientific domains. These advantages notwithstanding, Bayesian statistics is unlikely to replace traditional approaches, and there is no reason to reject *p*-values simply because they are often misused. The quality of the research is not dictated by one's choice of Bayesian versus Frequentist.

Reflections on an Emotion Dynamics Paradigm

This dissertation set out to understand solitude in terms of emotion dynamics. More precisely, the goal was to examine how social context influences patterns of emotional change – to answer questions such as whether being alone is associated with a different trajectory of emotion over time compared to being with others. Overall, this goal was achieved but only in its simplest respect. At this point, we reflect on how emotion dynamics was and was not represented in this dissertation’s research questions and methodologies, and contemplate future directions for research in this area.

Emotion dynamics posits that emotion is a continuous state, one that changes and self-regulates over time. Imagine one were to chart their affect over the course of a day in the form of a line graph, with time on x-axis and affect on the y-axis. They might see one or two lines (depending on which dimensions they measured) that are relatively steady for the most part, but with occasional peaks and valleys. Maybe there are moments when valence drops precipitously or rallies spontaneously. Or perhaps emotional events trigger an oscillating pattern in arousal (e.g., Chow et al., 2005). What is clear, however, is the complexity of these trajectories cannot adequately be described by *linear equations*. In other words, some amount of *non-linearity* is needed to understand what is happening. This could be in the form of using *ordinary differential equations* to examine how the rate of change in affect is impacted by time-varying covariates such as social context and momentary desire for solitude (Lougheed, 2020).

The lack of non-linearity in the current dissertation is therefore a serious limitation to its ability to speak to solitude and emotion dynamics. For instance, this dissertation offers some evidence that the magnitude of change in affect differs as a function of social context, but a more interesting question is whether the *rate of change* in affect differs. Rate of change is arguably

more relevant to emotion regulation, as it is concerned with how quickly one can recover from emotional events (Gross, 2015). Of course, the challenge in answering these questions about rate of change lies in the obtaining the requisite data. Emotion dynamics can only truly be unveiled with intensive longitudinal data sampled over brief intervals (max. 15 minutes) (Albers & Bringmann, 2020). Daily or even hourly intervals are too wide to capture complex patterns in emotion dynamics.

The dilemma is that sampling at increasingly narrower intervals is not only burdensome on participants, but at a certain point it confounds the experimental design altogether. A participant self-reporting their affect every minute will be too preoccupied with the questionnaire to experience interesting changes in affect! The current solution is to use so-called *passive sensors* to measure affect continuously and unobtrusively. Current examples include motion sensors and heat detection via Smart-Home technology (Nelson & Allen, 2018) and wearable audio recording devices to monitor speech for emotion words (Sun et al., 2020).

Passive sensing is applicable to the study of solitude as well. One innovation that has great potential for the understanding of how people spend their alone is passive Smart phone monitoring or *Screenomics* (Ram et al., 2020). Participants donate their Smartphone usage data to researchers, which includes information on what applications they are using at what time for how long (e.g., Instagram for 23 minutes, then played a game for 40 minutes). Participants can even agree to have their entire Smartphone display tracked by researchers.³³ This methodology coupled with periodic self-reported affect could be key to understanding how solitary activities (specifically screen-based activities) are linked with one's emotions over time. Taken together,

³³ Participants are still entitled to privacy. This is managed by allowing participants to review their data before it is sent to the researchers.

these innovative steps will be crucial to building our understanding of emotion dynamics and solitude at the minute scale.

Concluding Remarks: Resolving the Paradox of Solitude

We began with a paradoxical picture of solitude and well-being. Solitude has long been theorized to afford benefits in terms of creativity, restoration, and self-discovery (Buchholz & Catton, 1999; Larson, 1990; Suedfeld, 1974), but empirical evidence indicates that time spent alone is often unpleasant and undesirable (Epley & Schroeder, 2014; Wilson et al., 2014).

Accordingly, this dissertation proposed that a *Contextual Model of Solitude and Emotion* would bridge these apparently paradoxical views. Are we now any closer to resolving this paradox, and what does this mean for people's well-being?

The so-called *paradox of solitude* poses a false dichotomy: that solitude must be either all good or all bad. In contrast, this dissertation concludes that the relation between solitude and well-being is more nuanced. Solitude is associated with how we regulate our emotions and how our emotions change over time, but there is no evidence that this is universally good or bad. For instance, solitude increases the probability of choosing emotion regulation strategies that are both adaptive *and* maladaptive (on average). As well, solitude is associated with deactivation of arousal during negative emotional events, but this is not inherently restorative. Considering only these associations, solitude seems relatively neutral. However, consistent with our *contextual model*, the relation between solitude and emotions varies as a function of personality.

Extraversion is associated with whether one chooses to be alone or not, preference for solitude is (tentatively) associated with how one experiences solitude, and social avoidance is associated with how one regulates their emotions.

Thus, the *paradox of solitude* is ‘resolved’ so far as to say that there is no reality in which solitude is inherently beneficial or detrimental. Solitude’s impact on well-being is determined by the context in which it occurs. This is reflected in more recent work on solitude suggesting that each person may require a certain optimal amount of time alone. According to this view, solitude adheres to the *Goldilocks Principle*, whereby too much or not enough solitude is harmful. It is all about finding that balance that is ‘just right’ (Coplan, Hipson, et al., 2019; Coplan, Hipson, et al., 2021; Kidd et al., 2014).

Perhaps this has never been more relevant in a time where we are faced with a global pandemic – one that has forced people to physically distance themselves from their coworkers, friends, and family. In these trying times, many people are finding themselves with too much solitude, which puts them at risk for chronic loneliness and depression (Cacioppo & Cacioppo, 2018). On the other hand, some people are finding themselves with no time alone as they work from home surrounded by their family 24/7. Finding the right balance between solitude and social interaction may therefore seem more challenging than ever. Fortunately, there is evidence that human perseverance and ingenuity can help to overcome this challenge (Luchetti et al., 2020). For example, technology allows us to share moments with friends and family from a safe distance. It also allows school-age and university students learn remotely, although there are certainly some areas of improvement for remote learning. Moving forward, we should all consider how to achieve our optimal balance of solitude and social interaction and how to help others achieve this for themselves. This could start with reaching out to a friend who seems isolated, or maybe giving one’s partner an evening off to be in the solace of quiet solitude.

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Appendix A

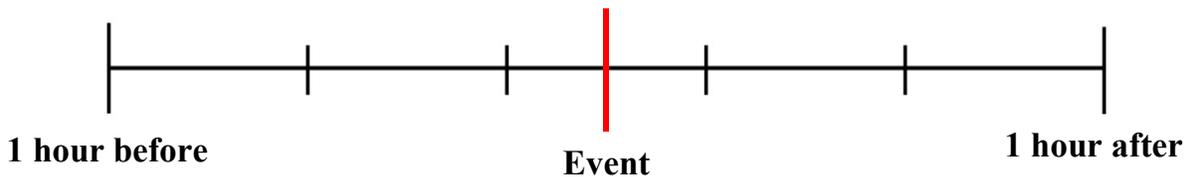
Event Affect Dynamics (Study 1)

(Positive and Negative versions presented in random order)

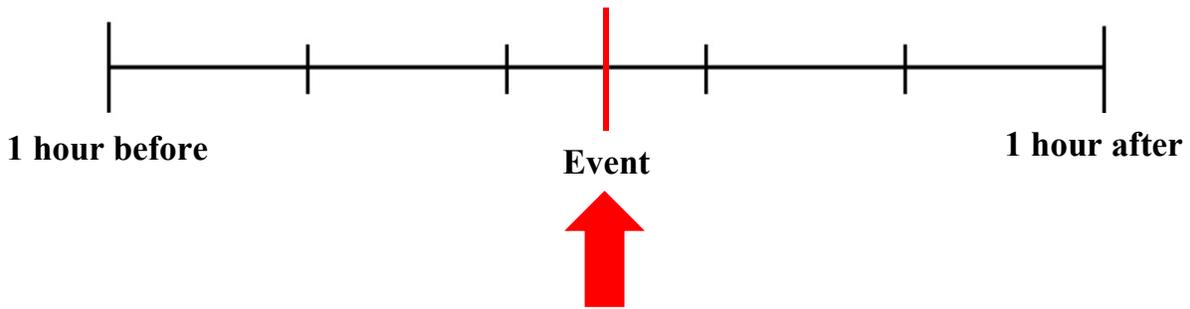
For the following questions we'd like you to recall the most **negative event** you experienced within the past 24 hours. That is, the event that led to the most negative emotions. (If nothing negative happened during this time, you can recall a negative event that occurred within the past 7 days).

Please take a moment to think back to this event and write a few words explaining this event in the space provided below.

Let's imagine this is a time scale of your event. The red line is when the event took place and the ends of the scale indicate 1 hour before and after the event took place. Click arrow to continue.



Answer the following questions, thinking back to the event *when* it occurred.



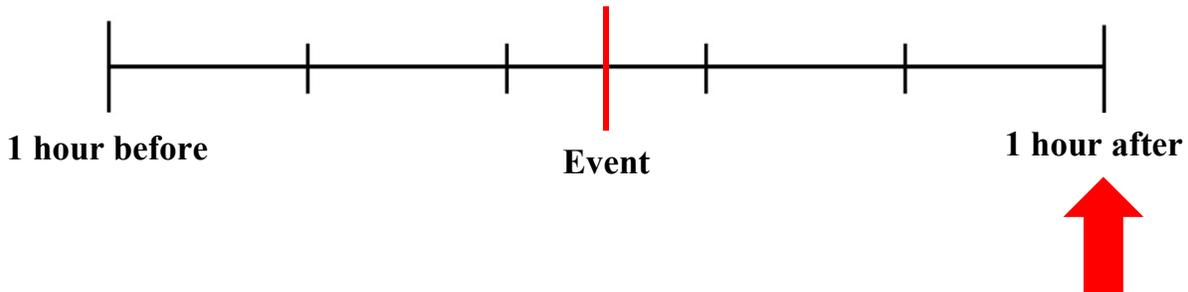
Rate how *pleasant/unpleasant* the event was for you.

- Extremely
- Moderately
- Slightly
- Neither pleasant nor unpleasant
- Slightly pleasant
- Moderately pleasant
- Extremely pleasant

Rate your level of *arousal* during the event (in this context, arousal refers to how **awake, alert, or activated** you were).

- Extremely low arousal
 - Moderately low arousal
 - Slightly low arousal
 - Neutral
 - Slightly high arousal
 - Moderately high arousal
 - Extremely high arousal
-

Now, answer the following questions thinking about how you felt 1 hour *after* the event took place.



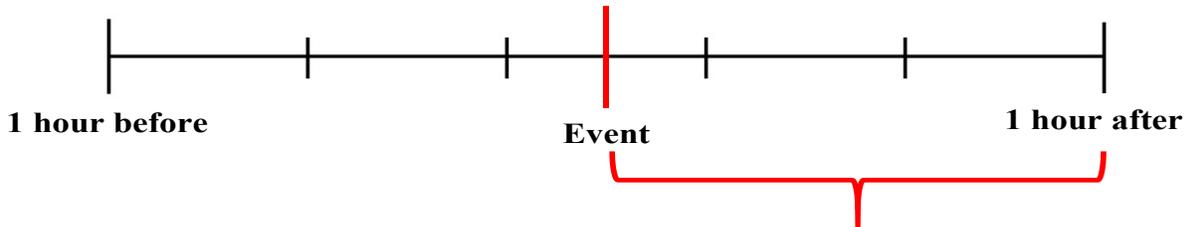
Rate how *pleasant/unpleasant* you felt 1 hour after the event.

- Extremely
- Moderately
- Slightly
- Neither pleasant nor unpleasant
- Slightly pleasant
- Moderately pleasant
- Extremely pleasant

Rate your level of *arousal* 1 hour after the event (in this context, arousal refers to how **awake, alert, or activated** you were).

- Extremely low arousal
 - Moderately low arousal
 - Slightly low arousal
 - Neutral
 - Slightly high arousal
 - Moderately high arousal
 - Extremely high arousal
-

Now, answer the following questions thinking about the time between when the event took place and 1 hour later.



During most of this time (within red bracket), were you alone or with others?

- Alone
- With Others but *not interacting*
- With Others and *interacting*

What were you doing during most of this time? Describe in a few words:

[Picture Shown Again]

Please rate to what extent you did the following during this time.

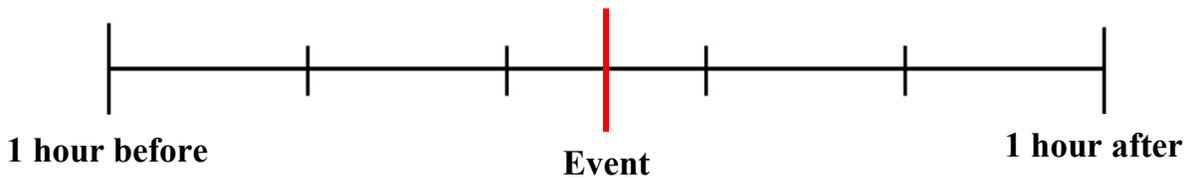
Not at all A little bit Somewhat Quite a bit A lot

1. Calmly reflected on my feelings
2. Changed the way I think about what caused my feelings
3. Couldn't stop thinking about my feelings
4. Avoided expressing my feelings
5. Engaged in activities to distract myself from my feelings
6. I have talked about my feelings with others

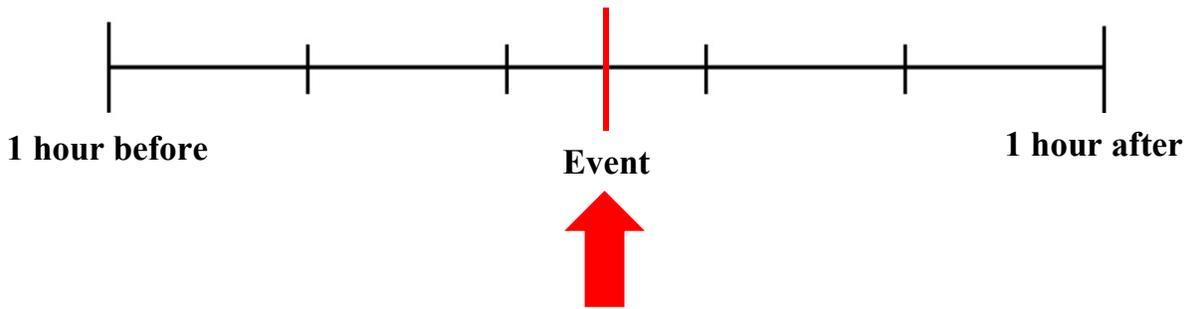
For the following questions we'd like you to recall the most **positive event** you experienced within the past 24 hours. That is, the event that led to the most positive emotions. (If nothing positive happened during this time, you can recall a positive event that occurred within the past 7 days).

Please take a moment to think back to this event and write a few words explaining this event in the space provided below.

Let's imagine this is a time scale of your event. The red line is when the event took place and the ends of the scale indicate 1 hour before and after the event took place. Click arrow to continue.



Answer the following questions, thinking back to the event *when* it occurred.



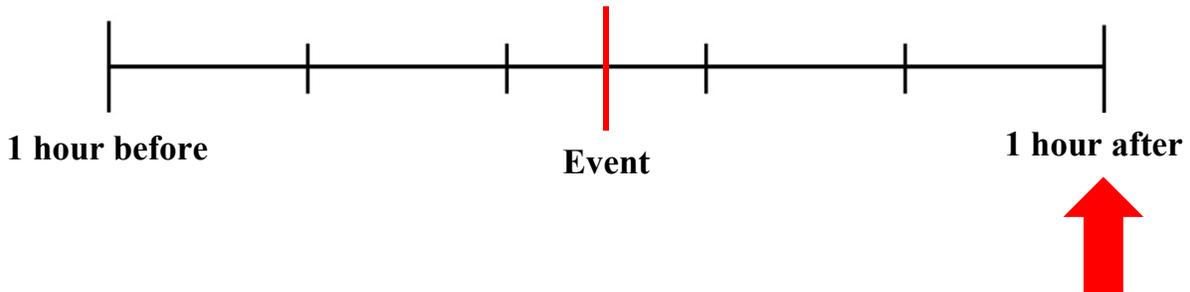
Rate how *pleasant/unpleasant* the event was for you.

- Extremely
- Moderately
- Slightly
- Neither pleasant nor unpleasant
- Slightly pleasant
- Moderately pleasant
- Extremely pleasant

Rate your level of *arousal* during the event (in this context, arousal refers to how **awake, alert, or activated** you were).

- Extremely low arousal
 - Moderately low arousal
 - Slightly low arousal
 - Neutral
 - Slightly high arousal
 - Moderately high arousal
 - Extremely high arousal
-

Now, answer the following questions thinking about how you felt 1 hour *after* the event took place.



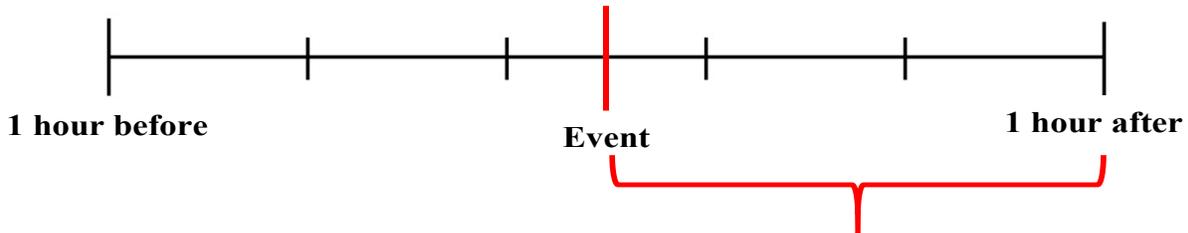
Rate how *pleasant/unpleasant* you felt 1 hour after the event.

- Extremely
- Moderately
- Slightly
- Neither pleasant nor unpleasant
- Slightly pleasant
- Moderately pleasant
- Extremely pleasant

Rate your level of *arousal* 1 hour after the event (in this context, arousal refers to how **awake, alert, or activated** you were).

- Extremely low arousal
- Moderately low arousal
- Slightly low arousal
- Neutral
- Slightly high arousal
- Moderately high arousal
- Extremely high arousal

Now, answer the following questions thinking about the time between when the event took place and 1 hour later.



During most of this time (within red bracket), were you alone or with others?

- Alone
- With Others but *not interacting*
- With Others and *interacting*

What were you doing during most of this time? Describe in a few words:

[Picture Shown Again]

Please rate to what extent you did the following during this time.

Not at all A little bit Somewhat Quite a bit A lot

1. Calmly reflected on my feelings
2. Changed the way I think about what caused my feelings
3. Couldn't stop thinking about my feelings
4. Avoided expressing my feelings
5. Engaged in activities to distract myself from my feelings
6. I have talked about my feelings with others

Appendix B

Coefficients for Model 2.2 using raw activity scores.

