Development of a theoretical approach for investigating the occurrence of boredom in animals

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Abstract

Many domestic and captive wild animals across the globe are kept under highly constrained conditions, and there has been a growing concern that boredom might represent a major source of welfare compromise for these animals. To understand how significant an impact animal boredom represents, there is first a need to improve understanding of what boredom is and how it can be recognised. The aim of this thesis is to systematically examine the concept of boredom and how it can be recognised in animals kept under human management. This investigation begins by reviewing current knowledge of boredom in humans, culminating in the presentation of a framework that demonstrates the relationships between the environmental antecedents, cognitive and physiological correlates, social and cultural features and behavioural outcomes of self-reported boredom. In humans, boredom is a temporally fluid emotion that is thought to function as a goal-switching signal, occurring when there is a mismatch between the availability of cognitive resources and environmental demands on those resources. The specific cognitive and behavioural changes associated with boredom are expected to change over time, but the pattern of these changes is not yet well characterised in humans, making it challenging to determine when to look for expected responses in animals.

The framework is then used to identify which aspects of boredom are measurable and manipulable to systematically investigate boredom in animals. While various correlates are theoretically measurable, the most promising measures of boredom are behavioural; three behavioural strategies are expected to occur in response to boredom, characterised as goal-switching, goal-perseverance, and non-goal-related behaviour. Manipulations to increase the likelihood of boredom-related behavioural outcomes involve altering either the availability of the subject's cognitive resources or the environmental demand, to produce a mismatch. A novel model is introduced to describe the predicted relationships between the expected behavioural pattern and the availability of cognitive resources relative to environmental demand, as well as perceived meaning of the current activity or task and the animal's judgement of control during boredom. The model predicts that when there is a resource-demand mismatch, or when an activity/task is low in meaning, boredom will prompt behaviours that aim to either change goals or regulate cognitive resources and demand to support persevering towards the current goal. In situations where the subject does not judge adequate control to successfully alleviate boredom through these strategies, the model predicts the occurrence of non-goal-related behaviours.

The model is used to investigate how existing research on environmental conditions and 'enrichment' (mainly through increased complexity) contributes to our understanding of boredom in animals. One important knowledge gap is understanding how a lack of change over time (i.e. monotony) is perceived as an antecedent to boredom in animals. The way monotony, so defined, may occur in the lives of animals is further explored. Although monotony is recognised as an antecedent of boredom in humans, it may not lead to boredom in all animals. The evolutionary background of a species is predicted to influence whether monotony is aversive to members of that species, and different types of monotony may be aversive to, or preferred by, different animals.

Consideration of the key features of monotony led to the development of an experimental paradigm for investigating the behavioural outcomes of task-related monotony in rats, with a view to observing whether the predicted strategies associated with boredom occur during monotony in a species that is expected to find such conditions aversive. The planned experiment could only be completed with a single animal, and the data recorded could not be fully analysed within the timeframe of this PhD. Nonetheless, the paradigm provides a potential method for investigating how monotony is perceived by animals and identifying any associated welfare impacts.

To date, there is a small amount of focussed evidence that animals in restrictive environments exhibit attempts to switch goals when opportunities are made available. However, most studies only report collapsed data such as the overall duration of different behaviours, precluding the recognition of behavioural patterns that indicate the occurrence of boredom according to the model developed here. Understanding these behaviours requires continuous monitoring to observe wider behavioural patterns over time. The model presented supports the systematic investigation of boredom in animals by generating predictions about the expected behavioural outcomes in situations with different features, which can be further examined and tested in future research.

The exploration of boredom presented here contributes to a growing area of animal welfare science. The recognition and alleviation of boredom are both important and it is hoped that this work will contribute to a strong foundation that will support and provide rigour to future studies.

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Publications completed in parallel with thesis research

Littlewood, K. E., Heslop, M. V., & Cobb, M. L. (2023). The agency domain and behavioral interactions: Assessing positive animal welfare using the Five Domains Model. *Frontiers in Veterinary Science*, *10* (**Appendix A**).

Chapter 1, Introduction and overview

1. Introduction to the problem of animal boredom

In humans, boredom is an unpleasant feeling that tends to arise in situations that are monotonous, overchallenging, and/or restrictive (Chapter 2, section 2.5). For various reasons, there is growing concern that some non-human animals may also experience boredom commonly and/or chronically (section 1.3). In particular, this concern arises because many animals are kept in unchanging environments with a high degree of behavioural restriction, which could predispose them to experiencing boredom. If animals can experience boredom, it would compromise their welfare, because welfare reflects the mental states of animals and is determined by whether they are pleasant or unpleasant. This would represent a substantial welfare issue because situations thought to lead to boredom are widespread across many animal-based contexts.

Boredom is challenging to study because it seems to be largely regulated by cognitive appraisals that cannot be directly observed (Chapter 2). Following from this, boredom is usually assessed in humans via self-report (Chapter 2, section 1.1) but this is not available in animals. To date, most experimental research relating to animal boredom has involved manipulating the complexity of the home environment and observing the animals' behavioural responses (i.e. environmental enrichment; Chapter 3). A small amount of work has also explored sensation-seeking in animals kept in barren (i.e. monotonous and restrictive) conditions (Meagher & Mason, 2012; Meagher et al., 2017). However, there is a need for the development of a systematic approach to understanding the antecedents, correlates, and outcomes of boredom in animals to support the interpretation of such research and the development of future investigations. In this chapter, I will introduce key concepts needed to understand the current state of knowledge, research gaps, and the approach taken in this thesis to progressing understanding of boredom in animals.

1.1. What is boredom in humans and why is it a problem?

In humans, boredom is an unpleasant experience (Vogel-Walcutt et al., 2012) that is often related to tasks or environmental conditions that involve a high degree of monotony or that are cognitively challenging and that the subject is restricted from leaving. Examples of such situations include classrooms and workspaces, as well as driving. Boredom is thought to motivate people to change goals when the benefits of persevering towards the current goal are outweighed by the costs of missing other opportunities (Danckert, 2019). As boredom is an aversive feeling, when opportunities to change goals are available, people will utilise them to alleviate it; this is observed even when those opportunities lead to other aversive experiences such as pain from an electric shock (Nederkoorn et al., 2016). However, when the subject is restricted from changing goals, boredom cannot be alleviated in this way and other behavioural strategies may be employed in attempts to mitigate the emotion. Boredom in humans is associated with a range of detrimental impacts such as problem gambling (Mercer & Eastwood, 2010), binge drinking (Biolcati et al., 2018), anxiety and depression (Brosowsky et al., 2022; Hughes, 2023), difficulty concentrating (Bambrah et al., 2023; Hughes, 2023), and emotional eating (Jackson et al., 2021).

1.2. Why might boredom be a problem in animals?

Because boredom is considered to be an unpleasant experience, it represents a source of potential welfare compromise for other animals that can experience it (Meagher, 2019). A common conception of animal welfare relates to how an animal experiences its life. This concept covers the dynamic interactions between an animal's physical function and health, the suitability of its environment and opportunities to express behaviour, and the mental experiences to which these factors give rise or influence (Duncan, 2004; Fraser et al., 1997; Weary & Robbins, 2019). Accordingly, welfare state at a given point in time reflects the multiple mental experiences that an animal is having, which may be hedonically positive or negative (Webster, 2016). Positive mental experiences such as comfort, playfulness, and goal-directed engagement are thought of as welfare enhancing, while negative experiences, including boredom, are welfare compromising (Mellor & Beausoleil, 2015).

1.2.1. Survival-critical and situation-related negative experiences

Within the category of negative or unpleasant experiences that can compromise welfare, two further subcategories can be considered and there are differences in the ease with which these subcategories can be investigated theoretically and experimentally. Survival-critical experiences are those needed to motivate actions that are necessary for survival such as hunger, thirst or pain. These kinds of negative experiences are essential for normal functioning because they promote crucial behaviours such as the seeking and consumption of food and water, or the avoidance of threats (Mellor, 2012). They operate via neurophysiological pathways that signal disturbances to the internal function of the body (e.g. nociception signals physical injury and leads to the emotional experience of pain) (Mellor, 2016). As such, survival-critical experiences are easier to study because they are linked to observable physiological changes.

On the other hand, situation-related experiences are those that relate to the individual's cognitive appraisal of the external situation and may include frustration, loneliness, or boredom. Many of these experiences do not seem to relate as clearly to specific physiological pathways or changes (Mellor, 2017), making it more difficult to identify observable measures related to their occurrence (see section 1.4 below).

Persistent or unrelievable negative experiences of either kind compromise welfare to a greater extent than those that are brief and can be readily relieved. If an animal is able to respond effectively to alleviate an experience, then the welfare compromise associated with that experience is considered to be minimal (Mellor & Beausoleil, 2015). On the other hand, if an animal is not able to respond effectively then the experience may persist and become more intense (e.g. increasing intensity of thirst when water is unavailable). This might occur because the cause of the negative experience persists (e.g. untreated disease or injury), because the resources required are not available, or because the animal is physically restricted from accessing them (e.g. food, shelter or companions). The impact on the welfare of the animal is more severe in such cases.

1.2.2. Terminology used to describe mental experiences

In describing mental experiences relevant to welfare, this thesis draws on knowledge from literature in human psychology and animal sciences. The terminology used in reference to mental experiences differs between these fields, so for clarity the terms used throughout this thesis are defined here, with justification for the choice of terms where appropriate. In particular, the terms emotion, feeling, and affect are common across disciplines but may be used with specific discrete meanings, or interchangeably.

Valence is whether the state is interpreted as hedonically positive or negative by the subject. A positively valenced experience is one that is interpreted as pleasant or desirable, and often leads to approach or seeking behaviours towards stimuli or events that the subject associates with that experience (Mendl & Paul, 2020). For example, excitement is a positively valenced experience that is often associated with desired and highly anticipated events. On the other hand, a negatively valenced experience is interpreted as unpleasant or undesirable and may lead to behaviours aimed at avoiding or removing stimuli and events associated with it. For example, fear is a negatively valenced experience that is associated with threatening stimuli. In the context of emotion, positive and negative represent the interpretation of the experience as pleasant and unpleasant respectively and do not necessarily relate to whether the experience is adaptive (i.e. promoting survival and reproduction), or otherwise useful (e.g. promoting competency in a particular skill).

In human psychology, an **emotion** is a valenced state resulting from neurobiological processes which may include experienced and non-experienced (i.e. unconscious, unaware) processes. In other words, some aspects of emotion may not be consciously 'felt' (Barrett et al., 2007). The term emotion typically refers to discrete states such as happiness, sadness, or boredom (Quigley et al., 2014). Because animals do not have shared conceptual knowledge (Bliss-Moreau, 2017; see Chapter 3, section 3.2), the term emotion is typically not used in animal sciences, or it is used interchangeably with the term feeling. Here, a **feeling** is the experienced component or sensation of a specific emotion (Duncan, 2004), which may also be called an **emotional experience** (Mendl & Paul, 2020; Prinz, 2005; Wilson-Mendenhall et al., 2013) or **felt emotion** (Weary et al., 2017). Many feelings may be experienced at one time, and, in the field of animal welfare science, the amalgamation of all feelings occurring at a given time is the individual's **mental state** (Mellor, 2016).

The term 'feeling' may also be used to describe the experience associated with physical sensations such as itchiness (Najafi et al., 2021). Experiences that are closely linked to physiological processes (e.g. survival-critical experiences such as pain and breathlessness) may be considered to have a sensory dimension and a cognitive dimension that are dissociable (Lansing et al., 2009; Peiffer, 2008; Price, 2000). The sensory dimension is not considered to be 'emotion' but is experienced or felt. In humans, boredom is widely considered to be an emotion (Elpidorou, 2021; van Tilburg & Igou, 2012) and the roles of sensory input and related physiological processes in the occurence of boredom are not well understood (see Chapter 1). Thus, here 'feeling' specifically refers to emotional experience or felt emotion.

The terms **affect** or **affective state** are used in both human psychology and animal welfare science. In human psychology, the term 'core affect' may also be used (Russell & Barrett, 1999). Such terms relate to the valence and arousal qualities of an experience, according to the circumplex model of affect (Posner et al., 2005; Russell, 1980). **Arousal** has many possible meanings (Chapter 2, section 2.3.1) but in the context of the circumplex model it generally refers to the level of energy associated with a feeling. A high arousal affect is a high energy experience and may be associated with a high degree of movement or restlessness. Both excitement and fear are high arousal affects, while contentment and sadness are low arousal affects.

In general, in animal welfare science 'affect' refers to states with valence (Mendl & Paul, 2020). However, in human psychology the arousal dimension is an integral part of the concept of core affect (Russell & Barrett, 1999), leading to potential confusion about whether arousal is implied when the term affect is used. In addition, the arousal dimension of boredom is contested (see Chapter 2, section 3.2.1) and it is currently unclear how boredom fits into the circumplex model. To avoid such confusion and the implication of a specific arousal state, the terms affect and affective state are not used in reference to boredom here.

Rather, in this thesis, boredom is referred to as an emotion or a feeling. This acknowledges that some aspects of boredom may not be experienced (e.g. parts of cognitive processing), but that scientific understanding of boredom in humans is largely based upon self-reports of *felt* boredom.

1.3. Potential for boredom in animals

Many animals are kept in conditions that might be expected to lead to boredom. Some of the animals anecdotally considered to be at risk from boredom include companion dogs left alone at home (Gibeault, 2023), zoo animals left to pace in bare enclosures (Stewart, 2002), research animals kept in small barren cages (Philbin, n.d.; Russiello, 2023), herds of cattle crammed into feedlots (RSPCA Australia, 2022), farrowing pigs held in narrow crates (SAFE For Animals, 2017), and racehorses isolated in stalls (Farm Transparency Project, 2020). These scenarios all involve two common environmental conditions: a high degree of monotony and behavioural restriction. These features lead to boredom in humans (see Chapter 2, section 2.5), suggesting that if animals can experience boredom then those housed in such conditions may be predisposed to welfare compromise as a result. However, from a scientific perspective, boredom in animals is poorly understood, largely because, with the exception of a few early publications (Wemelsfelder, 1985, 1993a, 1993b, 2008), it has only very recently become the topic of scientific inquiry (e.g. Burn, 2017; Meagher, 2019).

The consideration of boredom as a potential welfare concern has grown over the past decade, probably for several reasons. First, through decades of research in animal and veterinary sciences and technological advancement (e.g. vaccines), survival-critical experiences are now better understood and accounted for, allowing for focus to shift towards sources of welfare compromise that are related to the environments in which animals are kept (e.g. boredom, frustration, fear) as well as sources of potential welfare enhancement (Littlewood & Beausoleil, 2021; von Keyserlingk & Weary, 2017). In addition, more animals are housed in confined systems than in the past, particularly due to increasing numbers in intensive farming (FAO, 2023), as well as high numbers used in research (European Commission, 2023), and companion animals living more confined lives (e.g. in inner-city apartments).

Advancements in our understanding of animal ethology, cognition, and affective neuroscience also mean that the capabilities of animals are increasingly well understood and many species of animal are now recognised as being sentient, i.e. capable of having subjective internal experiences (Broom, 2010; Proctor, 2012). The study of animal welfare rests upon the assumption that some animals have some subjective experiences that matter to them (Mellor, 2016), an assumption that is increasingly well supported for vertebrate animals and a select few invertebrate animals (although some controversy is ongoing; see Browning & Birch, 2022). However, among animals considered to be sentient there is still much to learn about what kinds of experiences they might have. Having the capacity for some experiences does not mean that all experiences are possible. Thus, there is a need to explore and validate different kinds of experience, including boredom, in different kinds of animals.

From an evolutionary point of view, boredom is proposed to be adaptive for animals by promoting the seeking and uptake of novel or higher value opportunities. Burn (2017) proposes that from a phylogenetic perspective the animals most likely to have developed and conserved such an adaptation are generalists. Generalist species are those that are adapted to utilise a wide range of different resources, compared to specialists that are adapted to utilise only specific resources (Dennis et al., 2011). For example, rats are dietary generalists and can obtain and consume many different foods while some hummingbirds are dietary specialists and are morphologically adapted to access nectar from specific flowers (Rodríguez-Flores et al., 2019). Because generalist species are adapted to utilise varied resources, having a feeling analogous to boredom that motivates them to seek opportunities to exploit different resources is likely to be adaptive for these animals. On the other hand, such a feeling would be maladaptive for animals that are adapted to exploit specific resources.

Most species do not fit cleanly into a specialist or generalist category but have adaptations that support the exploitation of resources relevant to their evolutionary niche, such as food, water, shelter, or breeding partners (Dennis et al., 2011). Thus, generalism is relative to a specific resource. This means that the situations that lead to boredom may differ between species, depending on the availability of different resources. For example, a species that is highly specialised for exploiting a particular food source might be unlikely to feel bored due to restriction to that food source but may benefit from seeking new opportunities for social companions, mates or other resources and thus feel boredom related to those resources. Following from this, a wide range of species kept by humans may experience boredom.

For animals that can experience boredom, the experience might be expected to be more problematic than it is in humans. Compared to animals, most humans have a fairly high degree of control over their day-to-day lives and are able to perform actions that alleviate or lessen their experience of boredom when necessary. Even situations where they are restricted from taking such actions (e.g. work) usually last for a few hours at most. In contrast, many animals are kept in restrictive situations with a low degree of control over their environment and are not able to perform actions that alleviate or lessen any boredom. These situations are often long-term and continuous, with no break from the restrictive conditions to which they are exposed. Thus, if capable of the feeling, animals are considerably more likely than humans to experience severe welfare compromise associated with chronic, inescapable boredom. It is therefore important to develop ways to recognise when animals are experiencing boredom.

1.4. Recognising boredom in animals

Subjective experiences such as boredom cannot be directly measured, but they can be indirectly inferred through observable measures, called welfare indicators, that represent the function of processes relevant to specific feelings or emotions (Beausoleil & Mellor, 2017). Given that mental experiences are inherently subjective, any form of observation that steps away from the experiencing subject also steps away from the true nature of the state (Nagel, 1974). Following from this, welfare indicators can be considered at four levels of observation – each taking a step further from the experiencing subject. In humans, self-report is considered to be the closest measure of subjective experience because it captures the subject's own interpretation of their experience (Chapter 2, section 1.1). The next level involves "subject-based" indicators (called animal-based indicators in animal welfare science; Beausoleil & Mellor, 2017). These are measures related to measurable/observable changes that occur in the body of the subject – their physiology (Broom, 1991) and behaviour (Dawkins, 2004). One step further removed, "environment-based" indicators (resource-based indicators in animal welfare science) describe measures relating to changes in the environment that signify the potential for particular mental states to occur (Harvey et al., 2020). For example, an empty food bowl signifies the potential for hunger but does not on its own determine whether hunger is occurring for a specific individual subject. Finally, mental states may also be inferred through the judgement of another subject based on an integrated observation of subject- and/or environment-based indicators (e.g. qualitative behavioural assessment; Rutherford et al., 2012).

Inferring a particular mental state in animals requires the use of multiple welfare indicators (Broom, 1991). Self-report is not available in animals, so, in general, preference is given to subject-based indicators, as these represent the level of observation that is closest to the subjective state of interest (Beausoleil & Mellor, 2017). Survival-critical negative experiences are generally better understood in animals than situation-related experiences, because they can be assessed with subject-based indicators. These experiences have consistent neural and physiological correlates that are associated with the internal disturbances from which they arise, and behavioural outcomes that reflect efforts to mitigate them. For example, during dehydration raised plasma osmolarity is detected by osmoreceptors which transmit signals to brain regions associated with the experience of thirst, and as a result the animal seeks and consumes water (Denton et al., 2009). In contrast, situation-related experiences are challenging to study in animals, because their associations with measurable neural and physiological changes (and even with behavioural outcomes) are poorly understood.

So far, research explicitly focussed on animal boredom has instead assessed behavioural responses to environmental conditions that are thought to cause welfare compromise

(Meagher et al., 2017; Meagher & Mason, 2012), although some physiological indicators have been suggested (Burn, 2017). In these few studies it has been observed that animals housed in barren environments demonstrate a stronger motivation to access sensory stimulation (described as sensation-seeking) compared to those housed in environments that provide more opportunities for behavioural expression (Meagher et al., 2017; Meagher & Mason, 2012). This is consistent with the idea that boredom motivates the seeking of novel or higher-value opportunities.

However, other behaviours that bored animals are expected to exhibit do not seem to occur consistently under the same conditions. In particular, abnormal repetitive behaviours and lying still but awake have both been repeatedly suggested as indicators of boredom in animals (Burn et al., 2020; Burn, 2017; Meagher & Mason, 2012), but do not correlate reliably with sensation-seeking or occur consistently in environments expected to cause boredom in animals (i.e. barren or "unenriched" environments, Abou-Ismail et al., 2010; Polanco et al., 2021). Complicating the interpretation of this finding, these two behaviours are not commonly associated with boredom in humans but instead are drawn from ideas relating to the arousal quality of the emotion, which in itself is poorly understood (Elpidorou, 2021). These inconsistencies demonstrate a need to critically examine the concept of boredom as it is understood in humans to identify correlates that can be systematically explored in other animals.

2. Thesis aims, scope, and outline

The purpose of this thesis is to develop the theoretical foundations for understanding how boredom and its related concepts apply to animals kept under human management. This leads to the description of a conceptual framework that could be used to guide future research to develop critical knowledge for the understanding of animal boredom, and the use of that framework to evaluate animal boredom research to date and identify knowledge gaps. I then introduce a preliminary exploration of one component of that framework, namely monotony.

The thesis comprises six chapters that explore concepts related to boredom and their applicability to animals. Following this introduction to boredom as an animal welfare concern, Chapter 2 explores current understanding of boredom in humans and introduces a novel framework for understanding the complex, dynamic relationships among the environmental antecedents, cognitive and physiological features, social and cultural features, and behavioural outcomes of boredom. This framework is then applied in Chapter 3 in an exploration of how concepts related to boredom might be applicable to animals that are kept by humans.

Chapter 4 draws the focus of the thesis towards an important but understudied environmental antecedent of boredom: monotony. After presenting a theoretical approach to examining the potential roles of monotony in the lives of animals, Chapter 5 then outlines the development of a novel experimental paradigm for assessing how rats respond to a monotonous task. Due to substantial ongoing challenges (discussed further in that chapter), the planned experiment described in Chapter 5 could only be completed with a single animal within the timeframe of this PhD, and the data recorded could not be fully analysed in time for inclusion. Thus, as well as drawing together the conceptual understanding of animal boredom developed in the earlier chapters, Chapter 6 presents a pathway for further development of the task-based monotony paradigm and future research that builds on the theoretical foundations laid out in this thesis.

Given the limits to fundamental understanding of boredom in animals, I do not explore whether animals of any specific species, age, or other grouping experience boredom. Rather, I examine the information required to determine whether an animal has a mental experience that is comparable to human boredom in its function and manifestations, with a view to support future investigations of which groups of animals might have such experiences.

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Chapter 2, Current understandings of boredom in humans

1. Introduction

The concept of boredom has been understood differently throughout history, from using different terms to describe it (such as ennui, tedium, and existential malaise) to attributing different personality traits and conditions to those claiming to suffer from it, like hysteria or "alysosis" (Bergler, 1945; Ros Velasco, 2024). Academic interest in boredom has also taken varied approaches, from literature (e.g. Leroux, 2008) to philosophy (e.g. Levine, 2023) to psychology (e.g. Vodanovich & Watt, 2016). Modern scientific interest in the nature of human boredom is linked largely to challenges in three key areas: mental health, education, and workplace productivity and safety. However, despite decades of research, there is not yet scientific consensus on a definition for boredom, with researchers tending to focus on different aspects of the concept.

The purpose of this chapter is to describe how human boredom is currently understood, with a view to identifying key features and their interactions that may be relevant to furthering our understanding and ability to recognize the observable manifestations of a concept of boredom in other animals. To this end, the chapter focusses on research in psychology and does not systematically explore the history or philosophy of human boredom, as these aspects are ingrained in cultural and societal understandings that are less readily applicable to animals. I further acknowledge that in humans, the discussion of emotions is heavily influenced by language and culture (Dewaele, 2014; van Hemert et al., 2007), and that the scope of this chapter is limited to boredom as it is conceptualised in English within English-speaking or Western cultures.

In this thesis, the exploration of boredom stems from a concern for the welfare (i.e. mental state) of animals in specific conditions. Thus, the main focus here is furthering our understanding of how the concept of "state boredom" may be applicable to animals. State boredom is the transient experience of "being bored" (Elpidorou, 2021). This refers to the feeling of boredom that may be experienced in specific situations. On the other hand, "trait boredom" is the dispositional tendency of an individual to experience state boredom (Gana et al., 2019), i.e. the general predisposition to experience boredom. Trait boredom may also be referred to as boredom proneness and is associated with psychological conditions such as attention deficit hyperactivity disorder (Hsu et al., 2020) as well as certain individual personality traits such as impulsivity (Cao & An, 2020) and sensation-seeking (Jiang et al., 2009).

Although it seems likely that some animal species have individual variability in disposition that may be analogous to trait boredom in humans, understanding the role of these traits first requires an improved understanding of how state boredom applies to animals of different species and in different contexts. To illustrate, understanding whether one individual is more prone to experiencing boredom than another requires that we are first able to identify whether either individual experiences something like boredom at all. The current state of knowledge does not yet facilitate the recognition of state boredom in non-human animals (Chapter 3). Therefore, the focus here is on state boredom and use of the term boredom hereafter refers to state boredom unless otherwise indicated.

1.1. Use of self-report for identification and assessment of boredom in humans

Before discussing the characteristic features of boredom, it is necessary to understand how these features have been identified and studied in human psychology. The assessment of feelings in humans is fundamentally different from their assessment in other animals. This is largely because, for humans, the gold standard assessment tool for emotions is self-report (Harley, 2016; Westgate & Wilson, 2018). Self-report is the gold standard because it accesses the subject's interpretation of their experience (Robinson & Clore, 2002). As discussed in Chapter 1, emotion is inherently subjective, and any step towards greater objectivity is a step away from the true state (Nagel, 1974). Thus, subjective reporting is generally considered to be an acceptable approach to assessing emotion in humans. That said, there are several limitations that are important to understand when drawing inferences from self-report.

A key limitation of self-report is that it relies on honesty and assumes that the subject is able to accurately assess the parameter of interest. There may be individual differences in the extent to which people emphasize certain aspects of their subjective experience. For example, some people have a low focus on feelings of arousal and tend to rate high- and low-arousal feelings (e.g. nervousness and sadness, respectively) similarly, suggesting that they attend to the valence of the feelings more so than to the arousal quality (Barrett et al., 2004). The assumption that the subject is able to accurately assess their own experience is accepted because that experience reflects their unique subjective interpretation of their current state as modulated by their individual traits; this means interpersonal differences are taken to reflect variance in subjects' experience rather than assessment error (Barrett, 2004; Westgate & Wilson, 2018).

In studies relating to boredom, the research methods may influence the responses of participants. Some self-report paradigms directly ask participants "how bored are you?" (e.g. Danckert & Merrifield, 2018). In such cases, there is an implicit assumption that the individual participants understand the word "bored" similarly enough that they are all reporting about the emotional experience that the researcher intends to capture as "boredom". This method also leads participants to attend specifically to feelings of boredom. These feelings may not have been of particular importance to the participant before being asked or may have been overshadowed by other feelings, but this information is lost in asking directly for a report on boredom. Other paradigms seek to avoid these limitations by asking participants to report on feelings related to underlying aspects of boredom (section 2 below) such as tiredness or difficulty focusing (Baratta & Spence, 2018). As this chapter will demonstrate, the construct of boredom is not yet well-defined and single items (e.g. tiredness) do not necessarily correspond with experienced boredom in all contexts. Thus, these sorts of approaches are best performed using established multi-item scales that assess a range of items related to boredom, such as the Multidimensional State Boredom Scale (Fahlman et al., 2013; Vodanovich & Watt, 2016).

Despite the limitations of using self-report to understand and investigate human boredom, it is the closest we can get to confirming the state and validating the emotion associated with features that can be observed or measured, i.e. it is the best reference point available. Thus, throughout this chapter, I have used self-report as a basic requirement for considering the empirical evidence. In other words, when discussing evidence for boredom I only report findings that confirmed that subjects felt bored through self-report.

2. Key concepts associated with boredom

Broadly, boredom can be characterised as an aversive emotional state, associated with non-optimal arousal, attention deficits and a perceived lack of meaning, which promotes the pursuit of new goals (Eastwood et al., 2012; Elpidorou, 2021). However, our understanding of how processes such as arousal and attention interact and influence emotion is incomplete.

Although multiple accounts of boredom have been developed (section 3), they often overlap in their consideration of key concepts. Certain elements – including arousal, attention, agency, and meaning – permeate the theoretical models of boredom in humans and relate to the manifestations and assessment of boredom. This chapter presents a novel model of boredom that illustrates the relationships among these key elements (Figure 1) to support the investigation of boredom in animals that follows in Chapter 3. Here, the basic mechanisms and interactions of these factors are introduced to ground the subsequent exploration of boredom and application of human boredom theory to animals. First, two overarching concepts are introduced: temporality and agency. Next, the physiological, cognitive, social, and cultural features of boredom itself are introduced. This is followed by a discussion of the environmental antecedents of boredom and its outcomes that lead to, and/or are influenced by, these features.

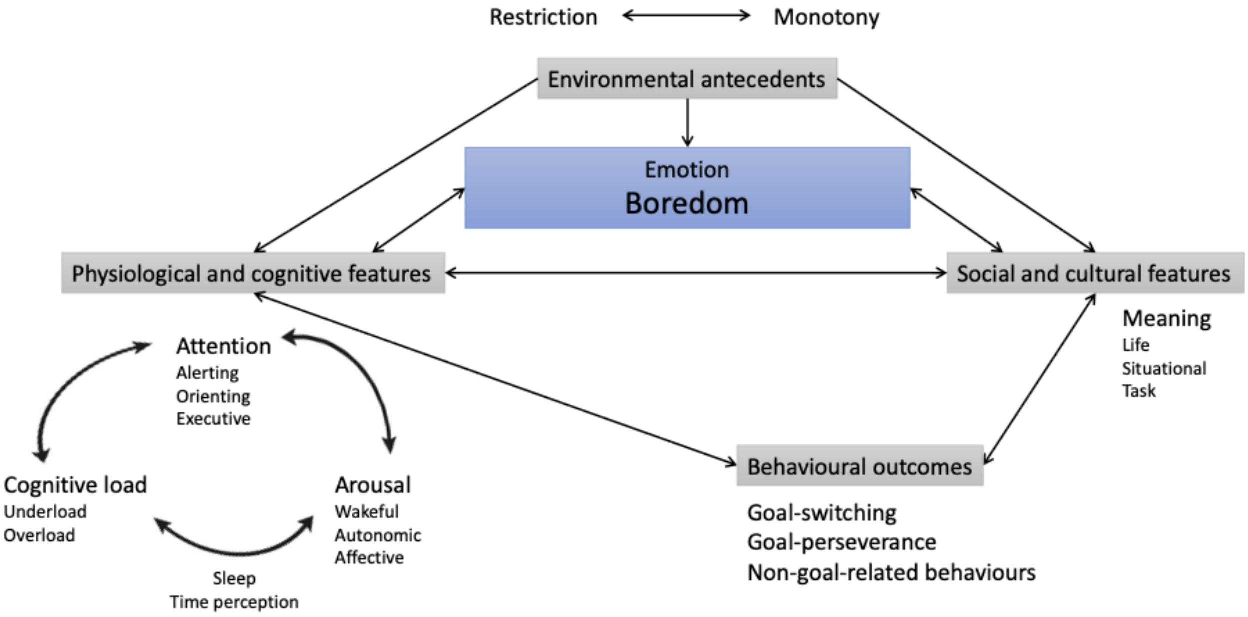

Figure 1. Theoretical framework outlining the connections between key boredom-related concepts in the human boredom literature.

2.1. Introduction to the roles of temporality in boredom

The passage of time plays an integral role in both the emergence of boredom and its manifestations. Boredom is thought to function as a signal that the current goal is insufficient/unsatisfactory and to promote goal-switching (Elpidorou, 2021; section 3.1.1). Thus, boredom emerges over time as the subject takes action in the pursuit of a goal, gains new information about the goal, and evaluates whether it is satisfactory. Following from this, the manifestations of boredom also change over time as the subject continuously gathers information about their current goal and available alternatives, attempts to alleviate the feeling behaviourally, and assesses the efficacy of their actions. For this reason, the role of time is alluded to throughout the following sections, leading to a temporal theory of boredom in section 3.3, discussed in relation to the correlates of boredom that will have been introduced by that point.

2.2. Agency

In the broadest sense, agency is the capacity to act intentionally or with reason, that is, to exhibit goal-oriented, voluntary behaviour (Mellor, 2016; Thomas, 2016). As boredom is thought to be a goal-switching signal, a subject must be capable of having goals (i.e. be an agentic individual) to experience boredom. Humans are generally assumed to have agency (Bandura, 2018), and animals that are considered to be sentient in a welfare-relevant way are also assumed to have agency (e.g. Englund & Cronin, 2023; Littlewood et al., 2023, Appendix A; Mellor, 2016; Špinka, 2019). This is because pleasant and unpleasant mental experiences are thought to function as drivers of goal-directed behaviour (e.g. fear drives the avoidance of threatening stimuli) (Broom, 2016; Mellor, 2016; Mendl & Paul, 2020; Wilcox, 2020). Related to agency are the interacting but distinct concepts of control, judgement of control, sense of agency, and judgement of agency, which relate to different features of boredom discussed later in this chapter.

2.2.1. Control

Control is the ability of agentic individuals to pursue goals and obtain desired outcomes (Leotti et al., 2010; Littlewood et al., 2023). The degree of control an individual has in a certain situation can influence the likelihood of boredom arising and their ability to alleviate it. Alleviating boredom requires the individual to take action to either regulate themselves or their environment, or to switch to an alternative goal (Elpidorou, 2021; Westgate & Wilson, 2018). If a person has a high degree of control then boredom occurs fleetingly, prompting them to take action to alleviate the feeling (Westgate & Wilson, 2018). On the other hand, when control is low, and the person can't take action or switch goals, boredom cannot be alleviated. Over time, this may lead to a chronic boredom state or the development of other mental states such as apathy or frustration (Bernstein, 1975; Gorelik & Eastwood, 2023).

The control of agentic individuals over their response to boredom may be restricted by factors that interrupt the contingency between their actions and desired outcomes (Fiske, 2018a). Intrinsic factors that may restrict control relate to perceived competence or skill (Bandura, 1977). Environmental factors include space allowance and access to structures, substrate, or manipulanda that facilitate the pursuit of a desired goal (Englund, 2023). Social factors relate to situations where another agent has control over a subject, such as through learned social rules (e.g. don't leave the classroom until the bell rings) or social hierarchy (e.g. don't leave the classroom without permission from a teacher) (Fiske, 2018b; Oettingen et al., 2008; Opp, 1982). Control may be discussed in an objective sense, whereby the absence of restricting factors in a situation indicates that an individual has a high degree of control. However, control also has a subjective element, as individuals must judge what actions are available to them. For clarity, here the subjective element of control is referred to as 'judgement of control'.

2.2.1. Judgement of control

To make a judgement about what actions are available to them, an individual must judge the affordances and restrictions present in their environment. Here, this is referred to as the individual's judgement of their control. Affordances are the behaviours that specific features of the environment enable (Gibson, 2014). For example, a chair affords sitting while a ladder affords climbing. Affordances are neither objective nor subjective, but straddle the divide between what exists in a space and the way that it is perceived, interpreted, and used by an individual. Thus, to determine their ability to perform a desired action in a given situation, an individual must identify the features present in the environment and make a judgement about whether those features afford the action. They must also identify any features that may prevent them from performing the desired action. A flat, stable surface may afford sprinting, but only if there are no walls in the way.

Unlike objective control, in which the opportunities for action can be objectively observed (e.g. a chair is available so the individual can sit), here a judgement is required by the subject about whether those opportunities are sufficient, based upon their own perception of the environment and their capabilities (e.g. a chair is available but the individual has lower back pain and doesn't feel that they can sit comfortably on that chair without a cushion). This judgement may be influenced by prior experience and learning (Gastelum, 2020), and by current personal factors that influence level of motivation (Siegel, 2014). Similarly to judgement of agency (see below), judgement of control is relevant to boredom because it influences the individual's perception of the cause of boredom and their ability to respond.

2.2.2. Sense of agency

While agency is the capacity to act intentionally or exhibit goal-directed behaviour, *sense* of agency is a feeling of having control over external events through one's actions (Haggard, 2017; Wen & Imamizu, 2022). In other words, the individual feels as though the actions they take have an influence on the world around them. Sense of agency is a quality of experience, or a background feeling of being in control. When an individual's control is restricted, they experience a lower sense of agency (Tapal et al., 2017), suggesting that a disrupted sense of agency corresponds with the occurrence of boredom (Eastwood & Gorelik, 2022).

2.2.3. Judgement of agency

Sense of agency is closely linked to, but dissociable from, *judgement* of agency (Moore, 2016; Synofzik et al., 2008). Judgement of agency is the attribution of causal control over events to the self or others. Consider a closed, empty room with a single person inside. The person walks around the room looking at the pictures hung on the wall and notices a crack in one of the frames. They reach out and lightly touch the crack to determine how big it is but when they touch it, the whole picture suddenly falls to the ground. In this moment, the person does not feel in control as the event was unexpected and non-intentional. Thus, they have a low *sense* of agency. However, the person is able to recognize that it was their action that caused the unexpected event to occur. They make a *judgement* of agency that attributes the causation of the event to themselves. When discussing human boredom, judgement of agency is important to consider as it may influence an individual's beliefs about the root cause of the feeling of boredom and their ability to resolve it (see section 2.5.2).

Related to judgement of agency is the concept of Locus of Control (LoC). This refers to individual beliefs about how controllable the environment is (Wang & Lv, 2020). LoC may be internal or external. People with a more internal LoC believe that their individual actions have an effect on their environment and that they have control over the environment through those actions. On the other hand, people with a more external LoC view the environment as uncontrollable and do not believe that their individual actions influence external events. Those with a more external LoC instead attribute control to external factors or processes, such as fate (Specht et al., 2011) or deities (Francis, 2020). LoC can be thought of as a trait component of agency, an enduring tendency to judge one's agency as low or high. In the context of boredom, LoC is important for meaning-making (section 2.4) but largely relates to trait boredom rather than state.

In the consideration of boredom in animals, the key concepts related to agency are control and judgement of control, because both are often limited when animals are kept in human designed systems. Throughout this thesis, situations where control is limited (or perceived to be limited) due to external influences are described as **restrictive**. These situations are discussed in the context of human boredom in section 2.5.2 of this chapter, and in the context of animal boredom in Chapter 3 (section 3.3).

2.3. Physiological and cognitive features of boredom

The key physiological and cognitive features of boredom, identified in the psychology literature on human boredom, are arousal, attention and cognitive load (Figure 1). Changes in time perception and the effects of boredom on sleep are also considered here. In the following sections each of these features is first introduced at the basic functional level before its role in boredom and interactions with other features are described.

The physiological and cognitive correlates of boredom are termed "features" here, as these processes interact closely with emotional processes and it is challenging to determine causality. Information processing (i.e. cognition) can bias emotion and vice versa (Boissy et al., 2007), meaning that these correlates may precede or cause boredom in some situations or may be essential parts of the experience (Elpidorou, 2023).

2.3.1. Arousal systems

Arousal is a highly complex process, scientific understanding of which has developed considerably in recent years. Boredom is generally considered to co-occur with non-optimal arousal, although many theoretical accounts postulate that it is a mixed-arousal state (e.g. Eastwood et al., 2012). In other words, the level of arousal associated with boredom is highly contextual and may change over time (Elpidorou, 2021), but is broadly considered to be non-optimal. Most uses of arousal in the boredom literature describe it as a unitary concept that broadly describes a measure of physiological activation or increasing activity (e.g. Baratta & Spence, 2018; Goetz et al., 2014; Westgate & Wilson, 2018). However, there is now evidence supporting the deconstruction of arousal into at least three interacting systems: affective arousal, autonomic arousal, and wakeful arousal (Satpute et al., 2019), all of which are relevant to understanding boredom in different ways and which might explain some of the difficulty understanding how arousal relates to boredom.

Scientific understanding of the relationship between boredom and arousal is currently based largely upon a combination of theoretical arguments (Berlyne, 1960; Eastwood et al., 2012; Elpidorou, 2021; Hebb, 1955; O'Hanlon, 1981) and a limited selection of empirical studies of boredom that assessed either affective or autonomic arousal, assuming the two are correlated (e.g. Goetz et al., 2014; Merrifield & Danckert, 2014). In contrast to this, I posit that rather than attempting to reach a conclusion about arousal as a unitary construct, there is value in exploring boredom's relationship with all aspects of arousal as distinct but interacting systems. As a heterogenous construct, the profile of arousal during boredom is likely to be complex and flexibly responsive to the varied situations in which boredom occurs. In line with this, evidence for the discrete roles of affective, autonomic, and wakeful arousal in boredom is considered here.

2.3.1.1. Affective arousal

Affective arousal refers to the subjective experience of arousal as described by human participants (Satpute et al., 2019). It can be thought of as how energetic a person perceives their feelings to be (Hanoch & Vitouch, 2004). In general, different emotions are thought to have consistent profiles of arousal and valence (Posner et al., 2005; see section 3.2.1). Anger, nervousness and excitement are often described as high-arousal emotions, while sadness, calmness, tiredness and sleepiness are described as low-arousal (Barrett et al., 2004; Fahlman et al., 2013; Raffaelli et al., 2018). In the case of boredom, identifying the level of affective arousal as either high or low is not so clear cut.

The investigation of affective arousal during boredom has produced conflicting results that seem to be related to the context in which participants are questioned about boredom. Two studies assessed boredom and arousal in participants outside of a controlled setting, during their day-to-day lives, and found that their arousal was low during boredom. In one study, participants carried a digital device for six weeks and were prompted multiple times a day to respond to questions about their current activity and emotional state, including "While engaging in this activity, how strongly do you feel boredom?" (Goetz et al., 2014). Whenever the participant selected a boredom rating higher than two out of five (Likert scale: 1 not at all, 5 very strongly), they would be asked "At this moment, how does it feel to be bored?". Arousal was also rated on a five-point Likert scale from 1 (calm) to 5 (fidgety) but no explanation of arousal was provided other than these two terms. Mean arousal levels reported during boredom were low but variation among individuals was wide (mean score 2.5, SD 1.25 and 2.05, SD 1.2 in two experiments). However, the correlation between boredom intensity and arousal level was not tested, so inter-individual variation in boredom ratings may have contributed to variation in reported arousal. Additionally, variability may be related to the situations participants were in when they reported boredom, trait factors including individual boredom proneness and tendency to focus on the arousal quality of their experiences, or how long they had been bored for when they were prompted to report.

Another study that supports the finding of low affective arousal during boredom used an online survey to ask participants about their experiences of 11 different negatively valenced emotions (e.g. sadness, frustration, disgust, fear), one of which was boredom (van Tilburg & Igou, 2017). For each emotion, participants were asked to rate various factors including arousal, described as follows: "Some emotions are associated with high levels of arousal (i.e. these emotions are very intense and make one feel alert) whereas other emotions are associated with low levels of arousal". Supporting the findings of Goetz et al. (2014), boredom was rated significantly lower in arousal than the ten other emotions. However, the description of arousal given to participants included potentially conflicting ideas by suggesting that high arousal emotions are both intense and involve high alertness. Not all intense experiences coincide with high alertness; for example, intense tiredness would be expected to make one feel low alertness. Given its relationship to wakefulness (section 2.3.1.3), boredom may be experienced intensely during periods of diminishing alertness. Thus, responses on the arousal appraisal may have reflected the choice of participants to report either how intensely they tended to experience boredom or how alert they felt when bored.

In contrast to the above studies, boredom has also been associated with reports of high arousal feelings such as restlessness, anxiety, irritability, and frustration (Harris, 2000; Martin et al., 2006). This apparently contradictory finding may relate to the context in which participants were asked about their boredom and arousal. Harris (2000) conducted a questionnaire that was distributed to university students near the end of a class session and filled out before leaving. When asked in an open-ended question to describe their feelings when bored, although some answers indicated low affective arousal (tired, empty/sad, low motivation), the most common answer was restless. Other answers indicative of high affective arousal included frustrated and anxious. Compared to the studies presented above, this context was considerably more restrictive; these findings could be related to the desire of the students to leave at the end of class or to get to their next activity on time.

In support of the idea that restriction might influence how people experience and describe boredom, van Hooft & van Hooff (2018) gave participants a series of tasks and manipulated their degree of control by either introducing the tasks with instructions that implied a high degree of control (e.g. "play around with the puzzles", "do them your own way", described by Sheldon & Filak, 2008) and allowing them to determine the order of tasks themselves (high control condition), or by giving instructions that implied a low degree of control (e.g. "you must do exactly as I say", "we can't let you have any choice") and determining the order of tasks for them. Whilst participants reported boredom across both conditions, those with low control also reported feeling more frustrated (indicative of high affective arousal) while those with high control reported feeling more "down" (indicative of low affective arousal).

Overall, the limited experimental evidence supports the idea that boredom is associated with mixed affective arousal, with reports of arousal seeming to be related to the degree of control participants have over their setting when asked about their experience of boredom. In less restrictive contexts, boredom is associated with low arousal while in socially constrained contexts (participants judge their control to be low), boredom seems to be related to high arousal emotions including frustration and restlessness.

2.3.1.2. Autonomic arousal

Autonomic arousal refers to the pattern of activation of the autonomic nervous system (ANS) and is usually measured through physiological endpoints such as heart rate, respiration rate, or electrodermal response (Satpute et al., 2019). The ANS is further divided into sympathetic and parasympathetic branches which are anatomically distinct and independently functioning, though it is their interacting effects that determine the resultant physiological outputs (Gibbons, 2019). The sympathetic division generally supports the body to sustain increased activity, for example by increasing blood flow through higher heart rate and increased blood pressure, so is referred to as the 'fight or flight' system (De Ridder et al., 2023). In contrast, the parasympathetic division supports the body to conserve energy during periods of relaxation and recovery, for example by decreasing blood flow through a lower heart rate and decreased blood pressure, and is referred to as the 'rest and digest' system. The responses coordinated by the ANS are mediated by neural and neurohormonal pathways (Gibbons, 2019), and are therefore generally fast acting and sometimes short-lived (e.g. heart rate may increase within three to four heart beats and recover within minutes; O'Gorman & Jamieson, 1977). Although responses from both branches act collaboratively to control the function of various organ systems throughout the body, in practice, "autonomic arousal" primarily refers to increased sympathetic activity. Thus, increased parasympathetic activity implicitly reflects a decrease in arousal.

In general, autonomic arousal during boredom seems to be moderate. It is usually assessed in comparison with other emotions, but there is a lot of inconsistency between studies (see Table 1). This seems to be related to methodological differences, as the role of autonomic responses during boredom has received limited attention. I reviewed 40 articles that have been cited as evidence of arousal during boredom in the last ten years and found only six studies that assessed a physiological parameter and confirmed the occurrence of boredom through self-report (Jang et al., 2015; London et al., 1972; Lundberg et al., 1993; Mavjee & Home, 1994; Merrifield & Danckert, 2014; Ohsuga et al., 2001). Based on these studies, boredom does not clearly fit into a high- or low-arousal description.

The most commonly used physiological measures in boredom research are heart rate (Jang et al., 2015; London et al., 1972; Lundberg et al., 1993; Merrifield & Danckert, 2014; Ohsuga et al., 2001) and skin conductance (Jang et al., 2015; London et al., 1972; Merrifield & Danckert, 2014). An increase in heart rate reflects an increase in autonomic arousal (i.e., sympathetic activation) (McCorry, 2007). The findings of various studies evaluating relative heart rate responses suggest that autonomic arousal is moderate during boredom. To illustrate, heart rate measured during reported boredom was found to be higher than during reported sadness (Merrifield & Danckert, 2014) but lower than during surprise (Jang et al., 2015) (Table 1). Heart rate during boredom was not significantly different compared to a relaxed-state baseline in one study (Lundberg et al., 1993) but was lower in another (Merrifield & Danckert, 2014) and equivocal results were found across various studies comparing boredom to 'interest' (Table 1).

The interest and boredom conditions varied in both kind and timing across studies. In one study participants wrote stories based on prompts (interest) or wrote the letters "cd" repeatedly for 30 minutes (London et al., 1972), in another participants first watched a video of two men hanging laundry (boredom) then watched a video of equal duration (233 seconds) of a clip from a nature documentary (interest) (Merrifield & Danckert, 2014), and in another participants were provided with magazines, games, and videos that had been previously rated as either interesting of boring and were encouraged to talk with one another in four sessions lasting from 30 to 35 minutes (Mavjee & Home, 1994). The discrepancy in findings between these studies could be related to the difference in timeframe, with heart rate not changing appreciably in the shortest boredom condition (233 seconds, Merrifield & Danckert, 2014), increasing over a moderate timeframe (30 minutes, London et al., 1972), and decreasing in the longest condition (two hours and 10 minutes total, Mavjee & Home, 1994). Additionally, the interest conditions might have caused different emotional states that influenced heart rate. Writing stories might have induced a state of focused engagement (i.e. flow, Peifer & Tan, 2021) for some participants, while watching a nature documentary could have involved feelings like awe (Bernstein, 2022), and social engagement with strangers could have led to varied feelings ranging from hurt (Gunther Moor et al., 2010) to happiness (Mote et al., 2019). Overall, the interest conditions are too varied across studies to draw meaningful conclusions about arousal during boredom, but studies comparing boredom to other emotions show a clearer outcome of a moderate arousal level between that of sadness and surprise (both confirmed via self-report). However, this conclusion is further complicated by the consideration of skin conductance.

Table 1. Summary of heart rate and skin conductance responses during reports of boredom, relative to during other reported emotional states. ⇑ indicates that parameter is higher during boredom than during the comparative emotion, ⇓ indicates lower during boredom, and = indicates not significantly different during boredom.

Comparative emotion	**Heart rate during boredom**	**Skin conductance during boredom**	**Reference**
Relaxed (baseline)	=	Not measured	Lundberg et al., 1993
	⇓	⇑	Merrifield & Danckert 2014
Sadness	⇑	⇓	Merrifield & Danckert, 2014
Interest	⇑	=	London et al., 1972
	=	=	Merrifield & Danckert, 2014
	⇓	Not measured	Mavjee & Home, 1994
Surprise	⇓	⇓	Jang et al., 2015

Skin conductance, also known as electrodermal activity or galvanic skin response, is related to the activity of sweat glands in the skin, which are under sympathetic control with no parasympathetic influence (Jang et al., 2015). Thus, in general an increase in skin conductance is taken to reflect an increase in autonomic arousal (Boucsein, 2012). While the findings for relative skin conductance were consistent with heart rate when comparing boredom to surprise (i.e. lower arousal), they were contradictory when comparing boredom to sadness and relaxed baseline. Skin conductance during reported boredom was lower than during sadness, suggesting lower arousal, while heart rate data suggested higher relative arousal (Merrifield & Danckert, 2014).

The discrepancies between heart rate and skin conductance demonstrate the occurrence of directional fractionation during boredom (Merrifield & Danckert, 2014). Directional fractionation describes the differential responses of autonomic indices (specifically heart rate and skin conductance) during situations that are expected to elicit a general and consistent change in autonomic arousal (Blaylock, 1972). This phenomenon is thought to relate to changes in skin conductance due to the engagement of attention (Blakeslee, 1979; Frith & Allen, 1983; Merrifield & Danckert, 2014). However, the findings presented above do not seem to support this hypothesis, as attention would be expected to be engaged during the interest conditions – particularly in the writing condition where attention would be required to perform the required task – resulting in a change in skin conductance compared to during boredom, but neither study reported here found a significant difference in skin conductance between interest and boredom conditions. This phenomenon makes it difficult to interpret these indices in this context and suggests that autonomic arousal itself is not a unitary phenomenon.

Given this challenge, it may be more instructive to consider the cardiovascular and integumentary systems as separate but interacting, allowing for nuanced consideration of their specific roles during emotion, including boredom. Ohsuga (2001) measured a range of cardiovascular responses during a monotonous task, in which participants performed a tracking task for twelve 5-minute sessions. Participants reported boredom that increased in intensity (rated on a Likert scale) over the duration of the experiment, and also showed an increase in respiratory volume and respiration irregularity (indicative of sighing and deep breaths). Other cardiovascular measures including heart rate, mean blood pressure and respiratory frequency increased during the first task session but recovered to baseline over the duration of the experiment. The correlation between reported intensity of boredom and the measured change in the physiological responses was not directly tested. Nonetheless this finding suggests that boredom may be associated with a consistent profile of some cardiovascular patterns over time.

Overall, the relationship between boredom and autonomic arousal is complex and incompletely understood. The only consistent result so far seems to be the finding that arousal during boredom is lower than arousal during surprise. It seems that boredom may also be associated with changes in cardiovascular activity, but further testing is required to confirm this relationship.

2.3.1.3. Wakeful arousal

Wakeful arousal refers to the activation of neural systems that promote and maintain wakefulness by stimulating cerebral cortical and sensorimotor activity and may also be referred to as cortical arousal (Jones, 2003; Satpute et al., 2019). Wakeful arousal (or wakefulness) is the “awake” state of the sleep cycle, characterized by the ability to respond to and interact with the environment, including cognitive processes such as attending, learning, remembering, and problem solving (Hirshkowitz, 2014; Oken et al., 2006; Scammell et al., 2017). Measures of wakefulness include electroencephalography (brain electrical activity; EEG) (Abad & Guilleminault, 2012) and performance in behavioural tasks such as reaction time tasks (Dinges & Powell, 1985; Sander et al., 2016). EEG is considered the gold standard for assessing wakefulness and has been used to characterize five stages of transition from high wakefulness (i.e. mental effort; stage 0) to sleep (stage C) (Sander et al., 2016). Stages 0, A, and B1 represent the "awake" stages that occur before sleep onset. As a subject moves from Stage 0 towards B1, they exhibit changes in cortical electrical activity, specifically alpha-wave activity, EEG signal amplitude, and eye movement that allow researchers to determine which stage they are in at a given time (Sander et al., 2016).

The connection between boredom and wakeful arousal has not yet been empirically investigated, but the association between self-reported boredom and feelings of lethargy and tiredness (e.g. Eastwood et al., 2012; Havermans et al., 2015; London et al., 1972) suggests that the role of wakefulness during boredom should be considered. Supporting this, an increase in self-reported sleepiness occurs when only "boring activities" are available (Mavjee & Home, 1994) and boredom is also associated with sleep disturbances (Lei et al., 2009).

Wakeful arousal moderates cognitive functions that are important to boredom, including attention (section 2.3.2) and working memory (section 2.3.3). For example, the effect of boredom on reaction time (see section 2.3.2.1, alerting attention) is stronger during the afternoon (12.50 to 15.50) than during the evening (18.50 to 21.50), indicating the involvement of circadian rhythms (i.e. cyclical changes in wakefulness throughout the day/night cycle) in the outcomes of boredom (Mavjee & Home, 1994). Thus, wakeful arousal may be particularly important to our understanding of boredom processes (also see section 2.3.5, boredom and sleep systems). Further research is critical to improve our understanding of the inter-relationships between boredom, decreasing affective arousal (specifically feelings associated with a need for sleep) and shifts in wakeful arousal.

2.3.1.4. Summary

Overall, changes in arousal associated with boredom are poorly understood. Affective arousal during boredom seems to depend on the context in which it is assessed and reported energy levels may be high or low. Autonomic arousal during boredom can thus far only be discussed relative to other emotional states and even then only in tentative terms; it appears to be lower than during surprise but not consistently different to sadness, interest, or baseline measures. Wakeful arousal during boredom has not been directly assessed.

At first glance, autonomic arousal seems as though it should correspond with wakeful arousal, whereby wakeful arousal should increase with sympathetic activity during periods of high behavioural and cognitive activity such as those associated with the perception of a threat (Löw et al., 2008). In many cases this may be true, but in some cases, increased parasympathetic activity is also associated with high levels of cognitive engagement requiring sustained wakefulness, such as during social engagement (Porges, 2003; Smith & Pollak, 2022). Thus, the level of autonomic arousal cannot be expected to always correlate well with wakeful arousal, which can complicate relating unitary 'arousal' and reports of boredom.

Theorists tend to explain these findings in two ways. Some suggest that, based on the above results and mixed opinions in early theory (e.g. Berlyne, 1960; Hebb, 1955; O'Hanlon, 1981), there is no characteristic profile of arousal in boredom (Danckert & Elpidorou, 2023). However, the findings described above demonstrate that changes do occur in the arousal systems during boredom. Currently it is challenging to determine whether or not these are characteristic of boredom, largely because arousal has been treated as a unitary construct in boredom research. Underlying this is the assumption that the three interacting systems described here are coordinated and therefore that their changes during boredom are correlated. However, as noted above, these changes do not always correlate strongly (Hanoch & Vitouch, 2004). High wakeful arousal may occur during periods of high and low autonomic arousal (i.e. during physical activity and relaxed concentration), while affective arousal seems likely to be influenced by both wakeful and autonomic arousal (e.g. feeling tired and anxious – both feelings that are associated with boredom). Further research is needed to explore whether any of these arousal systems independently show a characteristic response during boredom.

Another proposed explanation for the mixed arousal results is that boredom may have a temporal profile. This idea suggests that arousal changes over time during boredom and that mixed results are due to measuring at different timepoints (Eastwood et al., 2012; Elpidorou, 2021). Following this idea, the response of each arousal system during boredom may change over time, leading to moments of co-ordination interspersed by independent changes. For example, when boredom first occurs autonomic arousal might transiently increase as the subject takes action to alleviate the feeling, coordinating with a high degree of wakefulness that supports the subject to attend to their environment and take in new information about the options that are available for alleviating the boredom. If taking action does not alleviate the boredom, then autonomic arousal might drop as the subject stops moving, but wakeful arousal might remain high, allowing the subject to stay alert for any new information that might help them to alleviate the boredom. Over this time period, affective arousal may fluctuate depending on what actions are available, sometimes aligning with the activity of one or both of the other arousal systems. This idea is untested, but demonstrates a need for continuous (or in the case of affective arousal, closely spaced) measurement of markers that represent each of the described arousal systems. It also suggests that, when seeking to identify boredom in animals, observing patterns in arousal over time might be more informative than single measures.

2.3.2. Attentional networks

Attention is the concentration of cognitive resources towards a specific stimulus or set of stimuli to the exclusion of others (American Psychological Association, 2018). Boredom is often associated with deficits of attention which lead to difficulties in focusing on tasks (Eastwood et al., 2012). From an evolutionary perspective, attention allows an organism to maintain sensitivity to salient (i.e. important or prominent) sensory input, to filter sensory input according to what is most useful for it to be actively aware of (e.g. be aware of an approaching predator, rather than the colour of the sky), and to resolve conflict during sensory processing (Dukas, 2002; Lindsay, 2020). The ability to filter input and determine salience reduces demand on cognitive resources, but processing is required to determine which stimuli should be attended to and which should be filtered out. The result of this processing is selective attention, or the ability to engage in/focus on a specific activity (Plebanek & Sloutsky, 2019).

The ability to maintain attention relies on a match between the individual's available attentional resources and the demands on those resources created by the external environment (Danckert & Merrifield, 2018; Eastwood et al., 2012; Westgate & Wilson, 2018). In a familiar environment, attention is drawn towards changes; thus, in busy environments with many sources of change demands on attention are higher than in quiet, unchanging environments (Karacan & Hayhoe, 2008).

When attentional demands do not match the individual's available resources, attention is disrupted. This disruption of attention and resultant difficulty concentrating is thought to be an important feature of boredom (Eastwood et al., 2012). The successful engagement of attention relies on the functioning of three neural networks: the alerting, orienting, and executive attention networks (Posner & Rothbart, 2007). The following sections discuss current understandings of the relationships between each of these networks and boredom.

2.3.2.1. Alerting attention

The alerting network works to maintain a state of high sensitivity to sensory inputs or a high level of alertness (Posner et al., 2019). If alertness is too low then attention cannot be maintained and if it is too high then attention becomes high effort (Eastwood et al., 2012). The function of the alerting attention network is enhanced when sensory inputs are novel, salient, or changing (Pattyn et al., 2008; Robertson et al., 1997). This network is closely linked with wakeful arousal (Lindsay, 2020; Weinbach & Henik, 2013), and its actions are often conflated with arousal processes (e.g. Eastwood et al., 2012) due to this link (e.g. Jagannathan et al., 2018; Sengupta et al., 2017; section 2.3.1.3). The term "alertness" may be used to refer to either the alerting attention network or wakefulness itself. The alerting attention system may be assessed via performance in reaction time tasks, as a decline in alertness corresponds with a decline in sensitivity to sensory inputs, meaning that reaction time increases (Posner, 2008).

Boredom is generally thought to align with declining alertness (e.g. Cummings et al., 2016), but as with wakeful arousal this relationship has not been closely examined. One study found that, when responding to the repeated presentation of a randomly timed stimulus, reaction time was significantly longer after participants engaged in activities that were confirmed to be boring via self-report compared to after interesting activities (Mavjee & Home, 1994). This supports the idea that alertness declines in association with boredom.

2.3.2.2. Orienting attention

The orienting network is responsible for selecting salient information from the available sensory input and filtering out distraction (Eastwood et al., 2012; Posner, 2016). Studies of orienting network function typically manipulate distractions, for example by having participants select a target on a screen from a cluttered field of vision (Posner, 2016). Orienting to a stimulus in an empty field (i.e. with few distractors) is fast and efficient. Even if the individual knows they must monitor many potential target locations, they can orient their attention to a target appearing in a random location as efficiently as if they already know where the target will be (Duncan, 1980; Posner, 2016). On the other hand, if an individual has already oriented to a specific target, then it takes much longer to detect and reorient to a second target. Posner (2016) suggests that this is because there is a large cost to disengaging from an initial target.

Orienting attention processes may play an important role in boredom. If disengaging attention is expensive, then the cognitive processes involved in boredom may serve as an intrinsic mechanism to lower this cost and allow disengagement, promoting the reorienting of attention to a more beneficial target. This idea aligns with current functional theory, which suggests that boredom functions as an affective signal to change goals (section 3.1) but further evidence is required to determine whether boredom causes attention decrements or results from them.

Supporting the relationship between the function of the orienting attention network and boredom, the presence of distractions can influence boredom. When a distraction is obvious (a television playing loudly in another room), reported boredom is lower than when the distraction is subtle (a television playing with volume lowered) (Damrad-Frye & Laird, 1989 described by Eastwood et al., 2012). Obvious distractions may promote reorientation away from the current task towards the more salient stimulus – in this case the sound coming from the television – alleviating boredom associated with the task. In contrast, when the subject cannot identify the source of the distraction they cannot successfully reorient towards it and therefore cannot alleviate their boredom. Thus, it seems that boredom occurs when orienting attention is disrupted (i.e. when the subject cannot successfully reorient).

2.3.2.3. Executive attention

The executive attention network mediates the active control of attention by the individual and is responsible for the controlled use of attention over extended intervals. It is often associated with conflict between competing sensory inputs and is also involved in error prediction and inhibitory control (McConnell & Shore, 2011; Posner & Rothbart, 2007). To illustrate, executive control may be studied using a Stroop test (Figure 2) in which the participant is asked to attend to the ink colour (e.g. green) of a colour word (e.g. red) (Stroop, 1935). This requires the individual to pay attention to colour but to ignore the written word. The executive network is particularly important for tasks that require monitoring for rare or random events (e.g. medical monitoring). The function of this network is commonly assessed with vigilance tasks that require sustained attention to monitor for rare events, such as monitoring simulated flight paths for potential collisions (Danckert & Merrifield, 2018; Dillard et al., 2019).

BLUE	YELLOW	GREEN
GREEN	ORANGE	BLUE
YELLOW	GREEN	ORANGE
RED	GREEN	PURPLE
PINK	PURPLE	YELLOW
PURPLE	RED	BLUE

Figure 2. Example of a Stroop test. The subject is instructed to work through the table as quickly as possible by calling the ink colour, not the colour word. For example, the top right word would be called as pink, not green.

Feelings of boredom are often thought to arise in situations where an individual has difficulty voluntarily maintaining attention towards a given task (Eastwood et al., 2012; Pfattheicher et al., 2023; van Tilburg & Igou, 2012; Westgate & Wilson, 2018). This implies a deficit in executive attention processes. Although the specific attention networks are not often differentiated when discussing the association between attention and boredom, most experimental approaches use methodologies that assess the function of the executive attention network specifically, such as sustained attention or vigilance tasks. In these tasks, attention depletes over time (Eastwood et al., 2012; Pattyn et al., 2008).

Sustained attention tasks lead to reports of more intense boredom. The Starry Night task is a sustained attention task that requires the detection of rare events in a busy visual environment (Danckert & Merrifield, 2018). For 8 minutes, participants were shown a black background with around 250 white dots in random locations, resembling stars in the night sky, and asked to mark each appearance or disappearance of a single star. Immediately afterwards, they were asked to report “How bored are you right now?”. Compared to ratings taken after eight minutes of rest, participants rated their boredom significantly higher after performing the sustained attention task, suggesting that the intensity of boredom increases when attentional resources are depleted and maintaining attention is more difficult. This result aligns with earlier research that examined the time course of boredom using a different vigilance task (Scerbo, 1998). Self-reported boredom increased when assessed after five minutes on task and peaked at 10 minutes, then stabilized at the final measurement point at 15 minutes, while participants' vigilance performance (i.e. accuracy at responding to rare events) declined over time. This supports the claim that boredom occurs when the function of the executive attention network is disrupted due to depletion.

2.3.2.4. Summary

Unlike with arousal processes, when the distinct but interacting networks associated with attention are investigated independently, they show a consistent relationship with boredom. Boredom is associated with a decline in alerting attention and disrupted orienting and executive attention.

2.3.3. Cognitive load

Another important feature of boredom is the non-optimal deployment of cognitive resources, a process that interacts with both arousal and attention processes. Cognitive load refers to the current use of working memory resources relative to total available working memory resources, which may be regulated through actions such as exercise or caffeine intake (Morava et al., 2019; discussed further in section 2.6.2). Working memory refers to the temporary storage and manipulation of novel information before passing it into long-term memory, a requirement of most executive function tasks (Tempesta et al., 2014). Unlike long-term memory, working memory has a limited capacity for storing information (Sweller, 2011). When this capacity is surpassed (e.g. during a difficult task), it is referred to as cognitive overload and memory performance declines (Fox et al., 2007). On the other hand, cognitive underload occurs when available working memory resources are not utilized, such as during an easy task requiring little recall, and interestingly is also associated with declining memory performance (Blondé et al., 2022).

Cognitive load influences both attention and arousal processes. Sustained high cognitive load leads to a decline in wakeful arousal (Borragán et al., 2017) and is associated with low affective arousal feelings such as fatigue (Mizuno et al., 2011; section 2.3.1.1). Furthermore, cognitive load also influences orienting and executive attention processes. In executive attention tasks, high cognitive load (task difficulty) is associated with reduced distractibility (Brockhoff et al., 2022) and lower task performance (Hester & Garavan, 2005).

Reports of boredom are most commonly associated with cognitive underload, when available cognitive resources are underutilized. Many researchers intuitively use underload as a boredom-causing condition in task-based paradigms (e.g. Cherep et al., 2022), although often this condition is not directly validated through self-report measures as causing boredom. Nonetheless, boredom often occurs during tasks that are easy (Acee et al., 2010), unchanging (Havermans et al., 2015), or that are otherwise designed to require low cognitive load (Blondé et al., 2022). However, boredom is also associated with tasks that are challenging (Laybourn et al., 2022) or have a high information load (Acee et al., 2010). For example, students reported increased levels of boredom during classes that they perceived as being too difficult, suggesting that cognitive demand outweighed their available cognitive resources including attentional capabilities (Daschmann et al., 2011; Tanaka & Murayama, 2014). This implies that boredom also occurs during cognitive overload.

Boredom seems to occur when there is non-optimal cognitive load, either too low or too high (Westgate & Wilson, 2018). This suggests that there is an inherent value in using the 'optimal' proportion of cognitive resources, including both working memory and attention, as they are available. Following from this, boredom may be thought of as an affective signal that a person's cognitive resources are not being optimally employed, prompting a change in behaviour that promotes either an increase or decrease in cognitive load as needed (section 2.6).

2.3.4. Time perception during boredom

Another key hallmark of boredom in humans is a change in the perception of time. A common experience reported in association with boredom is that time seems to drag or move slower (Zakay, 2014). Psychologically, time perception involves both a judgement of duration and the experience of time passage (Witowska, Zajenkowski, et al., 2020). Judgement of duration reflects an individual's estimation of the duration of a given event, compared to the objective duration of that event. The subjective experience of time passage reflects an individual's experience of time passing relatively quickly or slowly.

Time perception is often assessed through self-report, but may also be studied using objective measures. Measures of time perception that don't involve self-report focus on accuracy during time interval estimation tasks. For example, Witowska et al. (2020) played a tone for 4, 8, or 16 seconds then played a second tone and asked participants to stop the tone when they thought it had lasted as long as the first tone. These kinds of objective measures haven't yet been used in relation to state boredom, but when asked to estimate the duration of a stimulus event, people with higher trait boredom (i.e. more boredom-prone) were more likely to overestimate the passage of time, suggesting that they felt the events lasted longer than they actually did (Danckert & Allman, 2005).

Studies using self-report to evaluate time perception are more common and the findings suggest that time dragging is perceived as unpleasant. In one paradigm, participants are asked to wait in a room without any time cues (i.e. clocks) for an undisclosed duration, then asked to estimate the duration of their wait (Witowska, Zajenkowski, et al., 2020). An alternative approach is to inform participants of the duration of a task, then manipulate the actual duration. For example, Weiss et al. (2021) used a ten-minute task but informed their participants that the task would last for five minutes (fast time condition) or fifteen minutes (slow time condition). Participants in the slow time condition rated the task as more aversive than those in the fast time condition, supporting the idea that the perception of time dragging is unpleasant.

Time perception is included in the boredom model presented here within the physiological and cognitive features domain (Figure 1). However, it is not clear whether changes in time perception are an outcome of more global effects of boredom on other cognitive features such as attention or whether they are integral to those processes. To demonstrate, although it is commonly believed that boredom causes changes in time perception, the relationship may be reciprocal. When the speed of clocks is experimentally manipulated, participants performing the same task report higher levels of boredom when time "moves slower" (London & Monello, 1974). This suggests that a change in time perception may itself cause boredom.

The relationship between time perception and boredom may also be modulated by attention. Allocating attention to a specific task may limit the availability of resources for attending to temporal cues such as changes in light quality and temperature. Thus, when an individual is engaged in a task and repeatedly misses external cues related to time passage, time may seem to go by faster (Eastwood et al., 2012), reducing the risk of boredom. Supporting this, in a visual search task requiring either high or low attentional engagement, participants overestimated the task duration to a greater extent in the low attention treatment, suggesting that they perceived time as moving more slowly (Chaston & Kingstone, 2004). Thus, time may seem to drag and boredom occur due to the associated attention deficits.

Further research examining the modulating roles of attention, arousal, and cognitive load on time perception during boredom may elucidate this relationship and clarify the placement of time perception in the model. Nonetheless, it is clear that during or due to boredom, time seems to slow down or drag.

2.3.5. Boredom and sleep

Arousal, attention, and working memory are closely related systems that all interact with wakefulness. Wakefulness is directly relevant to boredom because emotional experiences can only occur during wake phases and because low affective arousal states (fatigue, tiredness, sleepiness) relate to both wakefulness and risk of boredom (Baratta & Spence, 2018; Shen et al., 2006). In addition, the alerting attention network relies on a state of wakefulness to such a degree that "alertness" may be used to mean wakefulness and vice versa (Jagannathan et al., 2018; Shapiro et al., 2006). Likewise, deficits in other attention networks are associated with sleep deprivation and feelings of sleepiness and fatigue (Hudson et al., 2020). Optimal use of working memory also influences wakefulness. When sustained, a high degree of cognitive load (high demand on working memory) leads to decreased wakefulness but so too does cognitive underload; both conditions lead to reports of fatigue and tiredness (Hu & Lodewijks, 2021). As wakefulness is an integral part of the sleep/wake cycle, and given its relationship to arousal, attention and cognitive load, it makes sense that boredom is also linked with sleep systems.

Direct empirical evidence concerning the relationship between boredom and sleep is scarce, but the relationship between antecedents of boredom, such as monotony (section 2.5.1), and declining wakefulness (e.g. drowsiness; Jagannathan et al., 2018) is well established in the context of simulated driving research. Roadside monotony (such as repetitive features) leads to fatigue and drowsiness, evaluated through physiological measures such as EEG and subjective measures such as established sleepiness scales, and is a risk factor for driver safety as attention and performance decline (Bier et al., 2020). In addition, boredom may be implicated in sleep disturbances. In a survey of hospital patients, those whose self-report scores indicated poor sleep quality were considerably more likely to also report experiencing boredom during their hospital stay (Lei et al., 2009). This situation comprises a number of potential antecedents to boredom, including low control and monotony in terms of extended periods of time with minimal change occurring in the surroundings (section 2.5). Although these examples do not provide evidence of a direct correlation between boredom and sleep changes or disturbances, they suggest a need for further investigation.

2.3.6. Summary of physiological and cognitive features of boredom

The key physiological and cognitive features that have been associated with boredom are non-optimal arousal, disrupted attention, and non-optimal cognitive load. Boredom is also linked with a slower perception of time, which may be related to attention changes.

2.4. Social and cultural features of boredom

So far in this chapter, I have discussed the main physiological and cognitive systems that are associated with boredom and explored their interactions. However, in humans, emotion is influenced not only by innate cognitive processes, but also by socially constructed concepts like values (Ponizovskiy et al., 2019) and meaning (Maines, 2000). These constructs are thought to have adaptive value for highly social species by prompting the deployment of specific psychological defense strategies such as the pursuit of social connection through seeking relationships, and the defense of cultural views through in-group favouritism and out-group derogation (van Tilburg & Igou, 2012).

Meaning is particularly important to boredom theory (e.g. Westgate & Wilson, 2018; section 3.2.3). Meaning-making in humans is complex and multi-faceted, but is closely linked with boredom on several levels. A strong sense of life meaning or purpose is associated with low boredom proneness (trait boredom). For example, religious people reported lower feelings of boredom during a transcription task compared to nonreligious people; this low level of boredom was associated with a low desire to find meaningful engagement, suggesting these people either did not perceive the task to be low in meaning or that the effect of the low degree of task meaning was overcome by a sense of overarching life meaning (van Tilburg et al., 2019). Boredom proneness has also been associated with other cultural factors that influence life meaning such as political views (Van Tilburg & Igou, 2016). Thus, a stronger sense of purpose or life meaning makes people less prone to experiencing boredom.

Viewed another way, those with a strong sense of life meaning perceive their day-to-day actions as being part of a larger plan; for those people, situations or tasks that would otherwise be considered boring are accepted as necessary contributions to that plan (King & Hicks, 2021; van Tilburg et al., 2019). This ties in with the concept of agency explored above. For example, religious people tend to have an external Locus of Control, or ascribe control to their deity (Zarzycka et al., 2021). Such people may be less prone to experiencing boredom because they do not perceive a loss of control due to restrictive conditions (section 2.5.2) as they did not perceive a high level of internal control anyway. Thus, life meaning relates to trait boredom, a relationship that may be mediated by Locus of Control. However, the focus of this thesis is on state boredom, which is influenced by a different level of meaning.

State boredom is influenced by situational and task-related meaning. In other words, when a situation or task is not perceived as contributing to a larger plan or beneficial outcome, it is associated with boredom (Barbalet, 1999; van Tilburg & Igou, 2012). Task-related meaning may be thought of as the perceived value of task completion. In many cases, the value of completing a task is access to a reward (e.g. money or course credit), but it may also involve the impact or contribution of the task to a wider context, or gaining information that is relevant to other aspects of a person's life. To illustrate, when instructed to perform a 'boring' task, participants who were informed that they would receive a monetary reward reported finding the task more boring than those who were informed that the monetary reward would go to charity (Schmeitzky & Freund, 2013). Many experimental studies aiming to induce boredom involve tasks that are intended to be perceived as meaningless. For example, van Tilburg et al. (2019) used a task with contextual information that was unlikely to be relevant to participants (transcribe references to literature about lawn mowing), while other tasks involve responding to cues with limited contextual information (e.g. flashing lights; London et al., 1972) or no contingent outcomes (i.e. no reward for completing the task, e.g. Westgate & Wilson, 2018).

Likewise, a wider sense of situational meaning can influence perception of discrete tasks which might otherwise be boring. Tsai (2016) interviewed catering assistants and dishwashers whose day-to-day jobs involved repetitive, routine tasks such as clearing tables and placing cutlery and plates into a dishwashing machine. None of the 26 participants reported feeling bored at work and all mentioned that an interest in working in service industries kept them interested in their job. In addition, 21 of 26 participants mentioned a need for money as motivation, suggesting that these workers perceived a high degree of situational meaning which may have reduced their risk of boredom at work. However, this study did not assess individual factors that may have contributed to the worker's propensity to experience boredom at work, such as LoC.

Due to the complexity of interacting internal and external factors involved in boredom, it is challenging to determine direct causes of the state. Individual variability exists at multiple points including in agentic features such as judgement of control and LoC and cognitive features such as attentional and working memory capacity (Jarrold & Towse, 2006; Kyndt et al., 2012), which in turn influences the perception of task-related conditions such as difficulty and monotony (section 2.5.1). This means that the point at which boredom occurs varies widely, making it more difficult to elicit and recognize state boredom consistently compared to survival-critical experiences such as pain and hunger – particularly in animals where self-report measures cannot be used. Nonetheless, there are general features of the environment that predispose people to experiencing boredom and exploring these antecedents is instructive for recognizing environments that might be expected to trigger boredom in animals.

2.5. Environmental antecedents of boredom

Although a wide variety of specific conditions may be used to induce boredom experimentally, most of them manipulate aspects of two key features: monotony and restriction.

2.5.1. Monotony

In human contexts, monotony is typically characterized as a high degree of uniformity or repetition (Thackray, 1981). Broadly, monotony signifies a lack of complexity in a space (spatial monotony) or a lack of change across time (temporal monotony, e.g. high repetition or low event rate). The various ways that monotony may be present in an environment are discussed in detail in Chapters 3 and 4, but the focus in the current chapter is evidence of the connection between monotony and boredom. Here, I consider monotony to be an environmental condition that may lead to mental states such as boredom, either as a result of, or in association with, the physiological and cognitive processes that occur when it is perceived by an individual: cognitive load, attention, and arousal.

During monotony, the environmental features that support alerting attention (novelty, salience, and stimulus change; Pattyn et al., 2008; Robertson et al., 1997) are reduced or absent, meaning that attention must be sustained endogenously through executive processes. As mentioned above, executive attention depletes over time (Pattyn et al., 2008), supporting the general expectation that monotony causes disrupted attention (Thackray et al., 1977). Associated with a drop in attention is a shift towards a less wakeful state and associated feelings such as drowsiness (Gunzelmann et al., 2011; Oken et al., 2006). Aligned to this, monotonous tasks are associated with a wake state that oscillates between calm and active wake (Kiroi & Aslanyan, 2006), suggesting that wakeful arousal is influenced by monotony but that the duration of monotony also impacts this relationship. In addition to lowered wakefulness, autonomic arousal may also change under monotony, shifting to lower sympathetic tone (Floru et al., 1985), although this effect is inconsistent across studies (e.g. Fernandez-Guardiola et al., 1968). Over time, monotony results in decreased cognitive load as familiarity grows and no new or changing events need to be held in working memory. Thus, during the performance of a monotonous task the likelihood of boredom increases as performance improves due to repetition (Haager et al., 2018).

Monotony is often used to induce reports of boredom in humans experimentally (e.g. Bench & Lench, 2019; Havermans et al., 2015), and also occurs in paradigms that assess correlates of boredom such as sustained attention (e.g. Pattyn et al., 2008). In addition, humans avoid monotony when given the choice. To illustrate, when given a repeated choice between a variable or monotonous condition, participants consistently developed an avoidance bias against the monotonous option and chose the variable option on approximately 80% of trials (Seiler et al., 2022). There was also a positive correlation between monotony avoidance and reported boredom, meaning that participants who felt more bored were more biased towards selecting the variable option. In other words, the intensity of boredom was correlated with aversion to monotony. This result demonstrates the link between boredom and monotony and supports the idea that boredom functions as a signal to seek alternative or novel opportunities (section 3.1).

In real world situations, the link between monotony and boredom is less clear cut, likely because complete monotony is rare for humans outside of tightly controlled conditions, and efforts are made by people to reduce monotony when they have enough control over their environment to do so. Nonetheless, monotony is of particular concern in one common situation that restricts the control people have over their environment: the workplace (Loukidou et al., 2009). Workers report feeling bored during short-cycle repetitive tasks such as counting coins and inputting data (Fisher, 1987). In contrast to this, Tsai (2016) found that workers in catering did not report boredom at work, despite the high number of monotonous tasks required in their workday. However, a job rotation system was in place that allowed each worker to change between six jobs, performing one job for a day before changing to another. The workers therefore knew that the discrete tasks they had to perform on any given day would only be required of them for that day and that different tasks would be available tomorrow. This system was implemented specifically to reduce monotony and prevent boredom.

When monotony does occur, humans are generally able to respond by generating change – if not by breaking the monotony itself, then at least by circumventing it or limiting their exposure as the rotation system above did for the workers. Exceptions to this occur where humans have their control restricted by others, such as in prisons, hospitals, schools, or workplaces (Restriction; section 2.5.2). Thus, when considering the relationship between boredom and monotony, the individual's judgement of control is of importance. Nevertheless, monotony is associated with boredom across a broad range of contexts from classrooms (Macklem, 2015) to music listening (Merrill & Niedecken, 2023).

2.5.2. Restriction

Restriction is also linked to boredom, potentially occurring during monotony but also possible in complex, changing environments. Restriction may refer to physical or behavioural constraints that prevent a person from taking action (e.g. restraint such as handcuffs or confinement such as in a prison cell), social rules that make the desired action inappropriate (e.g. not leaving a classroom during class time), or the absence of stimuli that are judged sufficient by the individual to prompt or facilitate action (i.e. nothing to do). In all such conditions, restriction presents a limit on judgement of control – the perceived ability of the subject to pursue valued goals. All experimental paradigms used to induce boredom use restriction to some degree. This is because performing a task at the request of a researcher inherently places constraint on participants through social pressures. Participants may be restricted to a single task (e.g. complete an online survey) or space (e.g. wait in this room) or both (e.g. sit here and complete this task).

Restricted control prevents people from taking action to alleviate boredom through goal-switching or behaviours aimed at regulating themselves or the environment (see section 2.6). Because boredom is aversive, people only stay in a boring situation if they perceive some restriction from leaving or taking action to alleviate their boredom. In some circumstances, people will take action if it is available, even if the action has an aversive outcome like pain. For example, when left to view a video of the same 83 second clip repeated for an hour, participants chose to self-administer electric shocks at more than four times the rate of participants left viewing a documentary or movie for the same time period (Nederkoorn et al., 2016). This suggests that being restricted from taking action to switch goals when bored is unpleasant for people, to the extent that they will take opportunities to switch to other goals with unpleasant outcomes.

Restrictions may influence an individual's objective degree of control and/or their subjective judgement of control. In the context of restriction, it is important to avoid interpreting situations based solely on objectively measurable sources of restriction and to also consider intrinsic factors such as prior knowledge, expectations, and traits. In other words, just because it doesn't look like someone is restricted, doesn't mean they aren't.

To illustrate, during idle time at work, boredom could be experienced because control is objectively restricted when no work-related tasks are available, e.g. by social rules such as contractual working hours preventing the subject from leaving the situation. Alternatively, in the same situation, a worker might judge their control to be restricted if a work-related task is objectively available but they do not perceive it to be so (e.g. while their computer is updating they could take notes by hand but they have worked using the computer for so long that they no longer consider this as an option). In a longitudinal survey of German employees, self-reported idle time at work was predictive of reports of higher boredom (Zeschke & Zacher, 2023), suggesting that participants' emotional response related to their judgement of control in their situation.

Restriction often occurs in combination with monotony. Most monotonous situations are inherently restrictive because, by virtue of their monotony, they provide limited choices for goal-switching (see Chapter 4 for detailed discussion). Despite this, restriction is also associated with boredom in complex, changing environments. The waiting task is an example of a restrictive paradigm designed to elicit boredom. Here, the subject is misdirected with a fake reason for needing to wait and left alone in a waiting room for an extended and unknown period. At the end of the waiting period, the subject is asked to report on their experience. While the waiting task may take place in a monotonous environment containing no extrinsic opportunities for engagement or action (Witowska, Schmidt, et al., 2020), it may also take place in an environment with variety and opportunities for action, but with which subjects are instructed not to interact (Struk et al., 2020). Both situations lead to boredom, demonstrating that restriction can lead to boredom independently of monotony.

2.6. Behavioural outcomes of boredom

So far I have discussed the physiological and cognitive correlates of reports of boredom in humans, and the features of environments in which boredom reportedly arises. The following section examines how people respond to boredom behaviourally.

The direct behavioural outcomes of boredom are not well understood empirically. Three kinds of behavioural outcome are related to boredom in the experimental literature. Most studies focus on maladaptive behavioural strategies such as gambling and alcohol use (e.g. Biolcati et al., 2016; Mercer & Eastwood, 2010), but as these are most relevant to trait boredom (i.e. individual predisposition to boredom) they are outside the scope of this thesis.

More relevant, though less often studied, are the immediate behaviours that occur during state boredom. These may reflect goal-oriented behaviours directed towards alleviating boredom, or involuntary/reflex behaviours that occur during boredom. Currently, scholarly attention seems focused on developing theoretical models for patterns of intentional behavioural action in response to boredom (e.g. Elpidorou, 2021; Westgate & Wilson, 2018). In other words, researchers are interested in what actions people take to *mitigate* boredom when they experience it. This is a fairly new area of inquiry and there is limited empirical evidence to support current theory, but as intentional behaviours are used as key indicators of affective states in animal welfare science these theories are discussed here to provide insight into potential areas of investigation for boredom indicators in non-human animals.

Behavioural responses intended to mitigate boredom may either promote changing goals, or perseverance towards the current goal[1] (Westgate & Wilson, 2018). If the goal is not meaningful to the individual, then the chosen response may be to change to a more meaningful goal, i.e. goal switching. On the other hand, if the goal is meaningful to the individual, then they may attempt to mitigate the feeling of boredom by regulating the task, environment or self in order to complete the required task and progress towards that goal, i.e. goal perseverance (Westgate & Wilson, 2018).

In addition, a third category of behaviours develops when previous attempts at regulation have failed to alleviate boredom. These non-goal-related behaviours are of particular importance for the consideration of boredom in animals, as many animals are kept in settings that restrict them from taking action to regulate either their external or internal environments, or from pursuing new goals (see Chapter 3).

Involuntary behaviours associated with boredom can occur even when intentional, goal-oriented behaviour is restricted. Such behaviours may reflect both attempts to persevere at a goal or attempts to cope with inescapable boredom and are therefore discussed in both contexts in the following sections. Involuntary behaviours include changes in eye movements and posture. For eye movement, boredom is associated with increased rates of blinking and

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[1] Intentional behaviours prompted by boredom are most often described in reference to a specific goal or task (e.g. when someone is bored of doing something). Here, a goal is a desired event or outcome that an individual takes action to achieve. A task is a specific action or series of actions that is required in order to achieve a goal. For example, an important goal is obtaining food when hungry and the tasks required to achieve this goal include locating and consuming an appropriate food source. In some cases, achieving the goal requires undertaking tasks that can lead to boredom. Such tasks may be monotonous, predictable, and easy (leading to sub-optimal cognitive load, e.g. obtain food from a recently filled bowl), or they may be over-challenging and taxing on cognitive resources (leading to supra-optimal cognitive load, e.g. obtain food from a challenging puzzle feeder).

microsaccades – involuntary eye movements that occur even when the eyes are fixed on a specific location – that occur when viewing static (i.e. monotonous) images compared to when viewing moving videos (Welke & Vessel, 2022). In terms of posture, boredom is also associated with fidgeting (Ricciardi et al., 2020) and postural changes such as slouching and supporting the head with one hand (Bull, 1987; Doody & Bull, 2011). These involuntary behaviours are important to consider because even animals that are unable to perform intentional action may show similar signs of boredom.

2.6.1. Goal switching behaviours

When a goal is not meaningful, boredom may lead to goal-switching. In order to switch to a new goal, a person must first gather information to identify potential new goals and their relative value. Thus, reports of boredom are sometimes associated with exploratory behaviour (Geana & Daw, 2016) which functions to gather information about the environment. In the case of boredom, the information of interest is the available opportunities for engagement and the comparative value of those opportunities (Danckert, 2019). Exploratory behaviours occur *after* disengaging with the primary task and are therefore associated with the re-orienting of attention. They may include the active use of multiple sensory modalities such as visual, olfactory, and auditory search and investigation. In humans, exploratory behaviour may also include social engagement. For example, students may respond to boredom in the classroom by asking their teacher for alternate activities or talking with their peers (Nett et al., 2011).

Closely related to exploratory behaviour is sensation seeking. Sensation seeking may refer to a category of behaviours that facilitate seeking and engagement with sources of sensory stimulation (Burn, 2017) or to a personality trait reflecting desire for novel or intense stimulation (Arnett, 1994). The focus here is on sensation seeking behaviours. This term may be used synonymously with exploratory behaviours, but I propose that these two categories differ in function and therefore should be investigated separately.

Sensation seeking behaviours differ from exploratory behaviours in that they result in increased sensory input, but not necessarily information gain. For example, when left to view a monotonous video clip human participants repeatedly self-administered electric shocks (Nederkoorn et al., 2016). The first instance of this behaviour could be considered exploratory as it would provide information such as how painful the shock is and whether any contingent outcomes were associated with that action (i.e. if I shock myself, does anything else happen that might provide an opportunity for engagement?). After the first shock, there is a lower degree of information gain from subsequent shocks and this continues to diminish with repetition. However, some participants shocked themselves upwards of twenty times within an hour (Nederkoorn et al. 2016). This suggests that those participants were driven to seek sensory stimulation for its own sake, rather than to gather information.

Sensation seeking may result in interaction with aversive stimuli such as self-administered electric shocks, or appetitive stimuli such as food (Moynihan et al., 2015). However, even when appetitive stimuli are available, boredom may be correlated with an increase in the self-administration of aversive stimuli (Bench & Lench, 2019; Yusoufzai et al., 2024). The choice to engage with appetitive or aversive stimuli seems to relate to the stimuli that caused the boredom. When participants were repeatedly shown positive images to induce boredom, they were more likely to select exposure to negative images when given the choice, and vice versa (Bench & Lench, 2019). This phenomenon may be useful for distinguishing boredom from other emotional states such as anger, which are associated with the seeking of appetitive sensation (Meagher et al., 2017; Yusoufzai et al., 2024).

Another category of behaviour that may be associated with goal-switching due to boredom is novelty seeking (e.g. Bench & Lench, 2019). Both exploratory and sensation seeking behaviours may involve the seeking of novel or unfamiliar sources of information or sensory input. However, as demonstrated by repeated shocking, sensation seeking does not only occur when novel stimuli are available. Likewise, exploratory behaviour may occur in familiar surroundings, such as checking the fridge to determine what food is available for dinner. Novelty seeking specifically implies the seeking of stimuli that the individual has not encountered before, rather than familiar stimuli (Brooks et al., 2023). This may mean that the stimulus is completely novel to the individual or that they have not encountered it in the current context. The relationship between boredom and novelty is discussed further in Chapter 4 (section 3.2).

2.6.2. Goal perseverance behaviours

In contemporary theory, boredom is largely thought to function as an affective signal to promote goal-switching (e.g. Elpidorou, 2021). As a result, most empirical literature on boredom behaviours focusses on those related to seeking and engaging with new goals. However, a range of constraints may prevent people from changing goals, largely relating to social pressures such as the need to earn money or maintain social status. In some cases, the response of the individual to these constraints reflects the *meaning* the goal has to them. If a goal is meaningful, then an individual may be motivated to persevere in the tasks required to achieve that goal, despite feeling bored.

To promote perseverance towards a goal, an individual may seek to regulate external or internal factors that contribute to their boredom (Westgate & Wilson, 2018). External regulation involves behaviours that aim to alter the required task or adjust interfering environmental features to make the goal more attainable. Ways of altering the requirements of a task include reducing the difficulty by breaking the task down into more achievable steps; this may resolve boredom by changing the required cognitive resources, including attention and working memory, to more closely match the resources available to the individual (Westgate & Wilson, 2018). However, not all tasks are readily adjustable, so another strategy is to adjust environmental features through behaviours that reduce cognitive load by mitigating other sensory inputs (i.e. reducing distraction), such as blocking ambient noise. Such behaviours may directly mitigate the distraction at its source (e.g. turning off the radio) or resolve the effect of the distraction on the individual (e.g. putting headphones on or moving to a quieter location).

Internal regulation during boredom is theoretically associated with attempts to regulate the physiological and cognitive changes that occur. This category includes behaviours that influence wakefulness, attentional resources, and working memory resources. For example, rhythmic physical movement, or fidgeting, is commonly associated with boredom (da Câmara et al., 2018; Pattyn et al., 2008) and seems to reflect an attempt to increase autonomic arousal and promote wakefulness. Likewise, exogenous substances may be used to regulate internal features during boredom. For example, Westgate and Wilson (2018) suggest that caffeine intake may mitigate boredom by increasing wakefulness, which promotes improved executive attention thereby allowing the person to focus on their task.

When overt action is not possible, people may attempt to promote ongoing task engagement by reaffirming task meaning. For example, a particularly common response to boredom in school students is reminding themselves of why the current lesson is important (Nett et al., 2011). However, attempts to regulate boredom are not always effective and boredom may become prolonged or chronic. In such cases, regulatory behaviours such as those described so far may be interspersed with or replaced by non-goal-related behaviours.

2.6.3. Outcomes of failed regulation attempts

It is not always possible to change goals, or to regulate boredom effectively. Some situations restrict people's control to the extent that no alternative goals are available and regulatory actions are either impossible or ineffective. For example, during exams students are restricted from taking up tasks other than their test, cannot make changes to the environment of the exam room, have limited options for physical movement, and cannot access substances such as caffeine. In such situations, boredom is linked to behaviours that may help the individual cope with the feelings of boredom given that they cannot alleviate them.

Mind-wandering is a state of inward focus, where thoughts turn to subjects unrelated to the current task and external sensory environment (Smallwood & Schooler, 2015), and may be thought of as an unobservable behaviour (Critcher & Gilovich, 2010; Ricciardi et al., 2020). Mind-wandering allows the individual to disengage from their current task by following thoughts unrelated to that task. Thus, it is thought to relieve feelings of boredom by providing an opportunity to switch goals by engaging attention inwardly, thereby disengaging from external factors that are causing boredom (Smallwood & Schooler, 2015). However, mind-wandering may also exacerbate boredom by emphasizing discrepancies between the current (unsatisfactory) task or situation and potential (imagined) alternatives (Westgate & Wilson, 2018). Supporting this idea, participants who thought about a positive scenario during a simple task reported lower satisfaction with the task than those who thought about a negative scenario (Critcher & Gilovich, 2010).

In addition to mind-wandering, inescapable boredom may lead to behaviours associated with a loss of wakefulness and the onset of sleep. For example, patients confined for many hours to a single location reported using sleep to combat boredom during dialysis (Cheng et al., 2021). The established link between boredom and sleep-related feelings such as tiredness (Danckert et al., 2018; section 2.3.5) suggests that behaviours related to these feelings should occur during boredom. Behaviours such as yawning, stretching, and sighing are theoretically associated with boredom (Burn, 2017; Seuntjens, 2010; Toohey, 2011) but this relationship has not been empirically tested.

When confined to restrictive situations, people may perform highly repetitive behaviour patterns that do not have any apparent purpose (i.e. they are not goal-directed) (Ridley & Baker, 1982). For example, people in prisons may pace in their cells. These behaviours may be described as abnormal repetitive behaviours (ARB) or stereotypies (Garner, 2006; Ridley & Baker, 1982) but may also be described as fidgeting (Carriere et al., 2013). In animals, ARBs are regularly linked to chronic inescapable boredom (see Chapter 3, section 4.3.3). However, ARBs are rarely discussed in the context of human boredom. Nonetheless, humans have been shown to perform repetitive and purposeless behaviours during a waiting task, including tapping, rocking their bodies, and bouncing (Ryan, 2017). In addition, in the same test participants who scored higher on a self-report boredom scale also performed more ARBs. Such behaviours may reflect another kind of non-goal-related response that occurs when boredom cannot be effectively alleviated.

The discussion so far has focused on the individual features that are associated with boredom, providing an overview of the cognitive and physiological correlates, meaning as a social/cultural aspect, the environmental antecedents and behavioural outcomes. The next sections bring together current knowledge of these features to suggest how they interact during the experience, introducing various models that are used to make predictions about boredom in different contexts.

3. Current frameworks for understanding boredom in humans

In the field of ethology, behaviour is often described with reference to two categories of causality: ultimate and proximate (Mayr, 1961). Ultimate causality asks *why* an adaptation evolved over time in a population. Proximate causality asks *how* an adaptation functions in an individual. Another way to think of this is that ultimate causality is the evolutionary explanation while proximate causality is the mechanistic explanation. Although this approach was not intended for understanding cognitive or emotional processes, contemporary thinking accepts that such processes may have evolutionary bases (Öhman, 2006) making these kinds of causality applicable in this context. This approach provides an informative perspective on current theoretical models of boredom and how they relate to one another.

3.1. Boredom model that focusses on ultimate explanation

3.1.1. Functional account of boredom

The functional account of boredom focuses on the underlying purpose or ultimate cause of boredom as an emotion. This account defines boredom as a regulatory state that encourages the individual to pursue activities or goals that they find satisfactory (Elpidorou, 2021), or as a signal that facilitates disengagement from goal pursuit (Bieleke & Wolff, 2021). Here, satisfactory activities or goals are those that are perceived to be meaningful, interesting, or engaging to the affected individual (Danckert & Elpidorou, 2023; Elpidorou, 2021). Using this definition, boredom functions as both an affective signal and a motivational driver. The experience of boredom indicates to the individual that the activity or task in which they are currently engaged is of comparatively low value and motivates them to alleviate the aversive feeling by moving away from or avoiding the unsatisfactory situation (Elpidorou, 2021; Pfattheicher et al., 2023), thus promoting exploration (Bieleke & Wolff, 2021; Danckert, 2019).

According to this account, the ultimate cause of boredom is an evolutionary drive to reduce opportunity cost by motivating the seeking or uptake of novel or higher-value opportunities. Boredom achieves this by invoking a mental comparison between the current activity and available alternatives. It signals that, in comparison to alternatives, the current activity does not serve a useful goal (Bench & Lench, 2013) or allows the individual to determine whether the cost of continuing that activity is outweighed by the cost of missing another available opportunity (Westgate & Wilson, 2018). Unless the valued goal is explicitly focused on achieving a desired emotion (e.g. happiness), this theory posits that boredom does not discriminate between alternatives based on associated emotions (Bench & Lench, 2019). In other words, alleviating boredom does not require a person to switch to a task that invokes pleasant feelings.

When defined in this way, boredom is characterized by its outcome. This theory predicts that when bored, people will seek new activities that are either novel (value of activity not yet known) or of known higher value than the current activity. Boredom may be thought of as complementary to curiosity, as boredom signals the decreasing value of the current task while curiosity signals an increasing perceived value of other activities (Martarelli et al., 2022; Seiler et al., 2022). Thus, when bored, people should show shifts in attentional engagement with a particular focus on novelty or change and should explore alternative activities that demonstrate a potential for increased value, even if those activities produce negatively valenced feelings (Bench & Lench, 2013). From an evolutionary perspective, this allows for survival-related goals that involve aversive tasks, such as crossing a cold river to access a food source. In the case of sensation seeking (section 2.6.1), the value gain from interacting with aversive stimuli (e.g. self-administered electric shocks; Nederkoorn et al., 2016) may be the increase in sensory input itself.

The functional account does not discount other observed features of boredom such as attentional deficits and changes in physiological arousal, but argues that those features are part of boredom because they contribute to its overall function (Elpidorou, 2021); they are the proximate mechanisms that facilitate the ultimate function. These proximate mechanisms are not used to characterize boredom in this theory, because as long as the function is achieved, they may be highly discrepant among individuals and contexts.

The functional account is sometimes used to explain discrepancies in findings relating to proximate mechanisms, such as mixed results relating to the role of arousal (section 2.3.1). This is because under a functional account, varied proximate mechanisms such as cognitive and physiological features can give rise to the feeling of boredom and motivate goal switching. However, as demonstrated in this chapter, the cognitive and physiological features of boredom are not yet understood well enough to discount the presence of a consistent or characteristic profile of proximate mechanisms of boredom.

The functional account of boredom is strongly linked to the adaptive behavioural outcomes of boredom (i.e. goal-switching). In an evolutionary sense, goal-switching is adaptive because it promotes exploration of available resources and the uptake of high-value goals. However, in a modern environment this may be maladaptive. For humans, many desirable goals are abstracted from day-to-day tasks and actions. For example, an employee may persevere with boredom-inducing tasks because their goal is to earn money, get promoted, or keep their job in contrast to goals more directly related to survival like obtaining food. In such cases, goal-switching due to boredom would be maladaptive. Likewise, in highly constrained situations such as driving, alternative goals may not be available. This is particularly relevant to considerations of animal boredom, as animals are regularly maintained in highly constrained environments such as cages. Functional accounts of boredom do not satisfactorily explain situations where the adaptive function of boredom cannot be realized, i.e. the experience of boredom does not lead to goal-switching. Thus, proximate accounts are required to explain other outcomes of boredom that occur in situations where goal-switching is maladaptive or unavailable.

3.2. Boredom models that focus on proximate explanations

In contrast to functional accounts, proximately focused models of boredom examine the interacting roles of cognitive, physiological, and social mechanisms on the experience and outcomes of boredom. Two of the models discussed here include boredom within broader models of emotions, while the other two models are explicitly focused on the mechanisms of boredom.

3.2.1. Circumplex model of affect

The circumplex model of affect is often used to conceptualise emotions on a spectrum, as described in Chapter 1. According to this model, emotions are determined not only by their valence but also by the degree of arousal (Posner et al., 2005; Russell, 1980). Traditional accounts place boredom onto the model in a low arousal, negative valence space (Figure 3). However, this placement may be challenged for two reasons. First, the concept of arousal is not unitary (section 2.3.1) and has been used differently in different disciplines and research groups and second, the circumplex model does not account for changes in arousal over time.

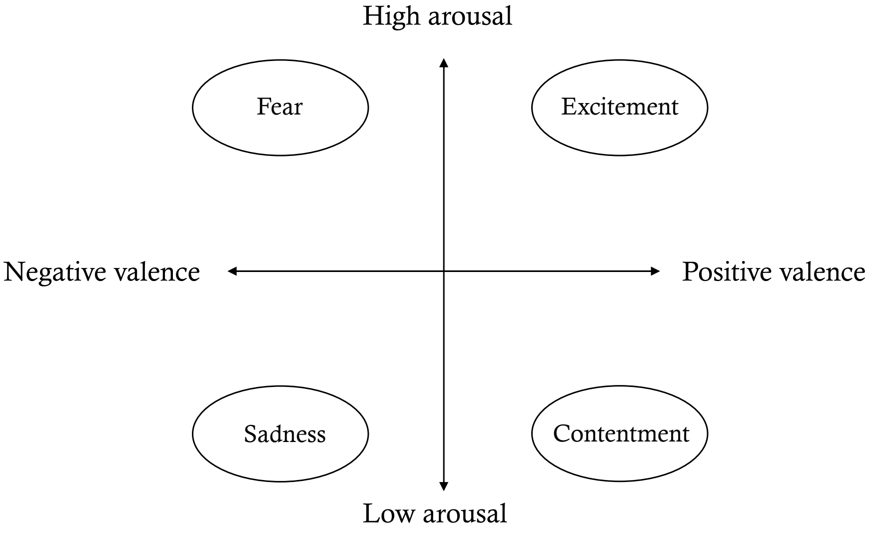

Figure 3. The circumplex model of affect adapted from Posner et al., (2005), showing the placement of four indicative affective states.

The placement of boredom as a negatively valenced experience is generally accepted. Across many studies, boredom is described by subjects as aversive or unpleasant (Vogel-Walcutt et al., 2012) and its function as a goal-switching signal depends upon the motivation to avoid or mitigate the feeling. Despite this, at least one author has discussed the possibility of a boredom subtype that has low positive valence. Goetz et al. (2014) describe a subtype of boredom called indifferent boredom which they propose occurs alongside relaxation and withdrawal, although the study does not empirically examine these co-occurrences. Other accounts link boredom to positively valenced experiences through its relationship with mind-wandering and creativity (Craven & Frick, 2024; Mann & Cadman, 2014). However, creativity may be more accurately considered as a response to boredom, rather than being a part of the boredom experience itself. Moreover, mind-wandering is often not an enjoyable experience (Wilson et al., 2014). Thus, in most models of boredom, a negative valence is accepted.

The original circumplex model presented arousal as the degree of wakefulness (Russell, 1980). In this conception, boredom is a low wakefulness emotion. However, the relationship between state boredom and wakefulness has not been empirically determined (section 2.3.1.3). Subsequent applications of the model have complicated the arousal dimension by using the term differentially and often failing to define it at all. For example, Posner et al. (2005) describe arousal as a neurophysiological state and discuss evidence relating to both autonomic and affective arousal. As discussed above (section 2.3.1), the profile of arousal during boredom is still poorly understood. Although it is often assumed to be a low arousal emotion, boredom seems to be associated with markers of high arousal in certain contexts (e.g. restlessness, Danckert et al., 2018). It seems likely that different arousal systems have distinct but interacting responses during boredom, necessitating a circumplex model that either clearly defines which arousal type is of interest or one that can account for multiple arousal types. Indeed, the arousal dimension of the circumplex model is under increasing scrutiny and is likely to continue being refined as our understanding of emotion improves (Satpute et al., 2019; Stanisławski et al., 2021).

Further complicating the use of the circumplex model for understanding boredom is the notion that arousal during boredom has a strong temporal component. For example, as discussed in section 2.6.2, behavioural responses to boredom may aim to influence the arousal systems (e.g. movement to increase autonomic arousal or wakefulness). The result of such behaviours may be an initial increase in arousal, but if they do not successfully mitigate boredom then this transient increase may be followed by a decrease in arousal associated with drowsiness or tiredness (Burn, 2017; Danckert & Elpidorou, 2023). Two important pieces of empirical evidence are missing here: how do the arousal systems interact during boredom, and what patterns do they exhibit over time during inescapable boredom? Until these questions have been further investigated, it is unclear whether the circumplex model requires a time axis to satisfactorily account for boredom, or whether refining the use of the arousal concept is sufficient.

3.2.2. Control-value theory of academic emotions

The control-value theory of emotion was developed as a framework for considering emotions, including boredom, related to academic performance (Pekrun, 2006). This theory posits that the two key factors influencing the development of emotions during learning are 1. the perceived control over the activity and outcome, and 2. the perceived importance of success in the activity. In the terms used thus far in this thesis, these factors are judgement of control and meaning, respectively.

In the case of boredom, control-value theory predicts a curvilinear (U-shaped) relationship between perceived control and boredom (Pekrun et al., 2010), meaning that boredom occurs in situations of both low and high control. This is based on the idea that boredom may occur when a student's ability surpasses the demand of a learning task (high control), as well as when the demand surpasses the student's ability (low control). The theory also predicts that boredom occurs when a task has low or no perceived meaning (importance) (Pekrun et al., 2010). This may occur when the overarching goal is perceived as unimportant, when the student does not understand what that goal is, or when the student does not understand how the specific task contributes to the goal. As predicted by the control-value theory, boredom correlates negatively with academic performance (Pekrun et al., 2010). The authors suggest that this finding can be explained by attention deficits that affect students' abilities to concentrate, ignore distraction, and stay engaged in learning-related tasks.

The control-value theory considers boredom in a specific context – academic performance. Thus, it largely focusses on the antecedents and outcomes of boredom that are relevant in an academic setting – that is, control and value perceptions for learning activities and the influence of boredom on academic performance.

3.2.3. Attention-focused models of boredom

Over the last decade, there has been an increasing emphasis on the role of attention as a proximate mechanism for boredom (Eastwood et al., 2012; Tam et al., 2021; Westgate & Wilson, 2018). Two models of boredom are discussed here, both of which emphasize attention but lead to different predictions about the situations in which boredom occurs.

The meaning and attentional components (MAC) model of boredom focusses on the proximate mechanisms of boredom, and, like functional theories of boredom (section 3.1), it considers boredom to be an affective indicator or signal. The MAC model builds on earlier theoretical work that emphasized the role of attention during boredom (Eastwood et al., 2012). This focus does not discount the role of other cognitive processes such as wakeful arousal or cognitive load but considers them as contributors to attentional resources. For example, wakeful arousal may be synonymous with function in the alerting attention system (Eastwood et al., 2012).

In the MAC model, attention and meaning are independent but interacting mediators of boredom (Pfattheicher et al., 2023). Attentional capabilities determine whether an individual is able to perform a task, while the perceived meaning of the task determines whether they want to perform it (Westgate & Wilson, 2018). The MAC model predicts that either attention deficits or a lack of task meaning can cause boredom, but that the experience of boredom differs depending on which is more dominant. The authors posit two boredom profiles: attentional boredom, occurring when task meaning is high and attentional resources are low, and meaningless boredom, occurring when attentional resources are high, but task meaning is low. In other words, the model predicts that boredom may occur when a person wants to engage in a task but can’t focus on it, and when they are able to focus but are not interested in their current task.

The MAC model does not discriminate based on the underlying cause of disrupted attention, predicting that boredom may be related to both under- and over-use of attentional resources (Westgate & Wilson, 2018). This is a departure from most contemporary understandings of boredom which focus on under-stimulation but aligns with ideas in cognitive load theory of under- and overload. In support of this idea, students reported increased levels of boredom during classes that they perceived as being too difficult, suggesting that cognitive demand outweighed their available cognitive resources including attentional capabilities (Daschmann et al., 2011; Tanaka & Murayama, 2014). Such findings may reflect both overstimulation due to difficulty and loss of meaning due to lower expectations of success.

This emphasis on attention is also evident in more recent theories such as the boredom feedback model (BFM; Tam et al., 2021). The BFM describes boredom as part of an attention feedback loop whereby it acts as a signal of inadequate engagement which leads to attempts to re-engage attention. Like the MAC model, the BFM acknowledges the interaction between attention and meaning. However, the BFM differs in that it does not view meaning and attention as independent factors. Rather, the BFM posits that meaning is a prerequisite for successful attentional engagement and therefore low task meaning leads to boredom because it interferes with attention. Another key difference is that it emphasizes the role of boredom in the appraisal of attention, so rather than viewing attention difficulties as a direct cause of boredom it views boredom as part of a continuous appraisal of changes in the engagement of attention.

3.3. A proximate model of boredom that accounts for the role of time

As noted in the introduction to this chapter, there is an inherent temporal element in the experience of boredom. In this section, I pull together the various elements discussed so far and present a general view of the role of time in boredom based on the findings. This account of boredom demonstrates the temporal fluidity of the emotion, aligning with recent theory that calls for the investigation of temporal patterns of boredom, particularly in its cognitive and physiological features (Danckert & Elpidorou, 2023; Elpidorou, 2021; Westgate & Wilson, 2018).

Boredom does not seem to occur in transient situations but rather develops over time as the individual orients to the environment, explores possible sources of engagement or change, and recognises any restrictions placed upon them. This assessment involves the use of cognitive resources to employ attention and working memory, which are supported by wakeful arousal. The outcomes of this orienting and information gathering process depend on the cognitive resources the subject has available and their judgement of control in the environment (Westgate & Wilson, 2018). If the subject has a high degree of perceived control and their available resources match with the demands of the environment, then they will be able to adequately engage in the pursuit of a goal that is meaningful to them and will not feel bored. If the subject has a low degree of control and cannot access a task with demands that align with the cognitive resources they have available then they will feel bored and will attempt to take actions to alleviate that feeling. If their actions fail to alleviate the boredom, then at some point they will give up and endure the boredom instead.

This general account of boredom is influenced at every stage by the effects of time on the many complex and interacting elements. The activity of the three arousal systems may change over time as the subject gathers information, alters their behaviour, employs cognitive resources, and attempts to regulate their situation when necessary. Attentional resources deplete over time when they are engaged, and the use of working memory resources leads to a decline in wakeful arousal, both increasing the risk of boredom developing.

If boredom is prolonged, the subject may also re-evaluate the meaning they associate with the tasks available to them, leading to changes in their judgement of control over the situation. As their familiarity with the situation grows over time, they may perceive monotony where they previously perceived a valuable source of engagement. Their behaviour may then lead to further change over time as they take action to support their cognitive resources or switch to goals that more closely align with the resources they have available. If these actions are not successful at alleviating the feeling of boredom, they may switch between strategies or go through stages of lethargy during which they seem to have given up on alleviating boredom at all. Elpidorou (2021) describes this as a process of cycling between agitated and apathetic boredom.

In the context of animals, this leads to a particularly important idea: that when boredom is inescapable, behaviours aimed at alleviating the feeling may repeat cyclically until the subject gives up. Given that repeated attempts at engagement probably also lead to physical and affective fatigue along with declining wakefulness, attempts at taking action to alleviate boredom may also decline in vigour and become less frequent over time. Ideas like this are generally less relevant for boredom in humans, because it is very rare for humans to be bored for more than a few hours at a time. But there is potential for prolonged, inescapable boredom across many animal-related contexts, so understanding how behaviour changes over time when boredom cannot be alleviated is highly relevant and is discussed further in the next chapter.

3.4. Summary

The functional model of boredom has been alluded to repeatedly throughout this chapter and has informed our understanding of the behavioural outcomes of boredom in particular. This model provides an ultimate explanation for boredom but does not directly explain the involvement of cognitive and physiological correlates (i.e. proximate causes) in the experience. In addition, the functional model of boredom generally assumes that the subject is able to carry out the function (i.e. switch goals). While this assumption generally holds for humans, animals tend to be subjected to a much greater degree of restriction that is likely to influence their ability to fulfil the function of boredom. Thus, to identify boredom in animals it is necessary to consider a range of correlates that are not directly explained by this model.

The proximate models of boredom all attempt to provide a mechanistic explanation for the occurrence of boredom. Seemingly as a result, the models introduced here focus on the relationship between two select features of boredom, using this relationship to explain other correlates. The circumplex model focusses on valence and arousal, Pekrun's theory of academic emotions focusses on meaning and judgement of control, and the MAC and BFM models focus on attention and meaning. While the development of a mechanistic understanding of boredom is important for ongoing research, it is not the purpose of this thesis. Rather, this thesis seeks to identify the correlates of boredom that can inform identification of boredom in animals. Using a single one of these proximate models of human boredom to examine boredom in animals would result in a narrower consideration of interacting processes and may lead to the loss of useful information. Based on the theoretical underpinnings of boredom examined in this chapter, another proximate model of boredom is suggested that presents it as a fluid experience that changes over time due to the influence of many interacting elements including cognitive processes, judgements related to control and meaning, and the success of behavioural attempts to alleviate the feeling.

At the current state of knowledge, a single model of boredom is not sufficient to examine boredom in animals. Thus, this chapter has introduced a framework to demonstrate the relationships between many possible correlates of boredom, that relate to the models presented here, as well as exploring the antecedents of boredom. This is not intended to provide a novel mechanistic explanation of boredom, but to visually clarify the many complex interactions among the antecedents, features, and outcomes of boredom that might be useful for recognizing boredom in animals.

4. Conclusions

The purpose of this chapter was to describe the current understanding of key concepts related to human boredom to inform the exploration of boredom indicators for animals in the following chapter. Boredom is a complex emotion that remains incompletely understood, even in humans who can verbally report on their experiences. It involves a dynamic interaction between cognitive and physiological systems and socially constructed meaning and is consistently preceded by exposure to monotony and restriction. The outcomes of boredom seem to relate to goal pursuit – either perseverance towards the current goal or the seeking and uptake of alternative goals. The precise interactions of these various features are not yet clearly understood, largely due to a need for more empirical evidence to support the various theoretical models that have been developed over the last decade. In addition, the role of time in the experience and correlates (cognitive, physiological, and behavioural) of boredom is poorly explored.

In this chapter, I have provided a framework to describe the basic relationships between the antecedents, correlates, and outcomes of boredom that previous researchers have identified as being important to the human experience. This framework focusses on the proximate features of boredom but differs from existing models in that it explicitly includes all of the described antecedents, features, and outcomes without emphasizing any in particular or attempting to provide a complete mechanistic explanation for boredom. In the next chapter, I will apply this nascent framework to explore how these features may be applicable to animals.

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Chapter 3, A systematic approach for investigating boredom in animals

1. Introduction

In recent years, boredom has been identified as a potential welfare concern for many animals kept by humans (Meagher, 2019). Therefore, there is a need to develop ways to recognise boredom in animals. Because boredom is an emotion and cannot be directly measured, understanding boredom in animals requires knowledge of the expression of the emotion in humans to serve as a foundation for inquiry. However, as demonstrated in Chapter 2, this foundation is still under development and the concept of boredom in humans is neither unitary nor broadly agreed upon. Researchers have developed different models of boredom that provide predictive tools for their particular research interests (e.g. control-value theory, Pekrun, 2006; Chapter 2 section 3.2.2) or that explain boredom at different levels (e.g. proximate explanations; Westgate & Wilson, 2018 or ultimate explanations; Elpidorou, 2021), but there is still no consistently agreed upon operational definition of human boredom. This leads to inherent challenges for the exploration of animal boredom, as our conceptualisation of the experience relies on an incomplete and contextually dependent understanding.

Further complicating the study of boredom in animals, the lives of many animals are different from humans in that they are controlled largely by external factors (i.e. humans). Many animals are kept in conditions that place considerable limits on their capacity to seek goals or engage in tasks that contribute to their goals (Littlewood et al., 2023). In other words, animals often have limited control over their environment. Following from this, animals in restrictive conditions are more likely to experience boredom and be less able to alleviate it. Another result of the tendency to keep animals in restrictive environments is that boredom in animals is typically thought to relate to their wider situation (e.g. Wemelsfelder, 1993a). In contrast, human boredom is usually linked to specific tasks that relate to the pursuit of an overarching goal (e.g. academic achievement; Pekrun et al., 2010). Thus, it is important to identify boredom correlates that are relevant to animals.

The purpose of this chapter is to utilise the framework of human boredom presented in Chapter 2 (Figure 4) to identify features of boredom that can be measured and/or manipulated in animals. I will apply a revised version of the framework appropriate for animals to review current evidence of changes in measurable outcomes that correlate with relevant manipulations.

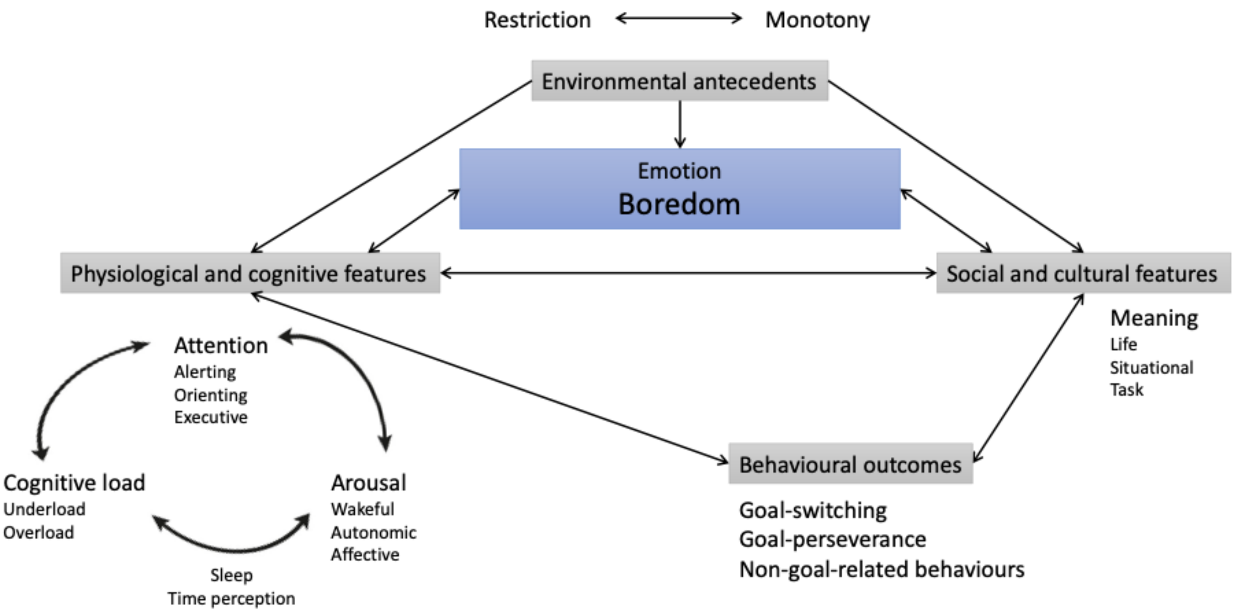

Figure 4. Theoretical framework outlining the connections between key boredom-related concepts in the human boredom literature.

As discussed in the previous chapter, the scope of this thesis is confined to the consideration of state boredom. It is likely that animals capable of feeling something like boredom also have traits that influence their individual proneness to experiencing the state. However, identifying such traits first requires an understanding of how the state of boredom can be recognised in an animal.

2. Overview of approach

As a subjective feeling, boredom cannot be directly assessed in animals. Nor can it be assessed through self-report; unlike humans, animals cannot describe their feelings or intentionally share a conceptual interpretation of their mental state. Instead, it is necessary to examine the observable correlates of boredom as they are understood in humans and determine whether they manifest in animals exposed to antecedents like those leading to reports of boredom in humans.

In this chapter, this examination takes place in three parts: first, by exploring which correlates of boredom can be measured in animals to facilitate investigations; second, by exploring which features can be manipulated to explore the effects on measurable correlates; and third, by evaluating whether the described manipulations have been found to associate with the expected outcomes in animal research to date.

This approach can be built upon in future research. For example, once reliable associations are found between manipulations (e.g. environmental features) and predicted outcomes, those outcomes may be considered valid indicators. If a reliable correlation exists between a boredom manipulation and resultant boredom indicators, then future research may identify additional outcomes that co-occur with validated indicators, contributing to the development of a suite of indicators that would further improve the recognition of boredom in animals. In turn, a robust suite of boredom indicators could be used to identify environmental risk factors for boredom in specific animals or group-level variations in boredom proneness (trait boredom). Current knowledge of boredom in animals does not yet support these developments, so further discussion of them lies outside the scope of this thesis.

3. Features of human boredom that are measurable in animal research

In order to undertake a structured investigation of any condition or state in animals, observable or measurable variables are necessary. The previous chapter identified a range of features that correlate with reported boredom in humans, which serve as a starting point for identifying potential indicators of boredom in animals. These were categorised as physiological and cognitive features, behavioural outcomes, social and cultural features and environmental antecedents. This section explores which correlates are measurable in animals.

3.1. Physiological and cognitive correlates

The cognitive and physiological features of boredom introduced in Chapter 2 provide a range of potential subject-based indicators that could be used to improve our understanding of boredom in animals. Such indicators would be preferable over environment-based indicators, because they access processes that are more closely related to the subjective experience (Chapter 1, section 1.3). As discussed (Chapter 2, section 2.3), it is still challenging to determine whether the cognitive and physiological correlates of boredom are causes or outcomes of the emotion or if they are an integral part of the experience itself. In addition, the relationships between reports of boredom and some of these factors are still ambiguous.

Nonetheless, if carefully evaluated, accounting for the sensitivity of such factors to time and conflation of non-unitary features, these provide a useful starting point for identifying potential indicators of boredom in other animals.

3.1.1. Arousal

Of the three types of boredom-relevant arousal identified in humans, only autonomic and wakeful arousal are currently measurable in animals. Affective arousal is accessed in humans through self-report (Chapter 2) and thus is not directly accessible in animals.

Patterns of autonomic arousal may be measured directly through a suite of endpoints including cardiovascular indicators such as heart rate, heart rate variability (von Borell et al., 2007), respiratory rate (Burn, 2017), and pupillary response (Karemaker, 2017). As an integumentary indicator, skin conductance may also be of use in some species but its application is limited to animals with sweat glands (e.g. horses; Golzari et al., 2023).

Wakeful arousal may be assessed by monitoring behaviours related to sleep such as sighing, yawning, or blink rate (Burn, 2017). In addition, EEG monitoring could be used to identify the stage of wakefulness. EEG has previously been used to characterise wake states in rats (Corsi-Cabrera et al., 2001). However, care is required as patterns of EEG activity when awake are variable among species (Lancel, 2008). This means that to compare findings in animals with those in humans there is a need to characterise the specific changes in cortical electrical activity that correspond with different stages of wakefulness in each species studied.

Awake inactivity may also be useful as a behavioural indicator of wakeful arousal. Awake inactivity is a behaviour characterised in mammals by remaining still with eyes open, indicating that the animal is not asleep (Burn, 2017). Currently it is not clear precisely how awake inactivity relates to wakefulness – lying still may reflect low behavioural activity, but remaining awake implies the maintenance of a degree of wakeful arousal. To explore whether this behaviour reliably correlates with wakeful arousal, EEG activity could be characterised to determine whether there is a consistent profile (e.g. activity in a specific frequency band that indicates lower wakefulness than during behavioural activity). In addition, the interpretation of this behaviour would be aided by examining whether the animal eventually moves into a sleep state, which would suggest that awake inactivity represents a stage in the transition to sleep.

The relationship between sleep and boredom has not been empirically investigated in humans, but once future research has investigated this knowledge gap it may lead to an improved understanding of boredom-responses related to fatigue and sleepiness, which are in turn related to wakeful arousal. Sleep can be recognised in animals behaviourally or through EEG (Rattenborg et al., 2017), and these measures are better characterised in animals than EEG activity during wakefulness. Wakeful arousal can theoretically be measured in animals, but there is a need for further development of EEG and behavioural measures to facilitate the interpretation of findings.

Overall, the most promising boredom-indicators based on concepts of arousal during boredom are behaviours related to sleepiness such as yawning, sighing, and blink rate. These behaviours are likely to reflect low wakeful arousal specifically, although all three arousal processes are inter-related.

3.1.2. Attention

Like the emotion itself, the cognitive correlates of boredom cannot be directly measured but they may be assessed indirectly through related behavioural and physiological outcomes. As noted in Chapter 2, boredom is associated with disruptions in all three attention networks (alerting, orienting, and executive). Thus, in theory, the three networks can each provide potential measures relevant to investigating boredom in animals.

Changes in behaviour may be used to assess the function of the executive attention network in humans during sustained attention or vigilance tasks (e.g. Robertson et al., 1997). In such tasks, the key parameters are rate of error (i.e. responding when the target is not present), and reaction time (Cheyne et al., 2006; Gunzelmann et al., 2011; Robertson et al., 1997), but the interpretation of these parameters depends on the specific test. Some tasks designed to require vigilance and sustained attention have been adapted for animals (Salmon et al., 2023). For example, rats can be trained to perform a signal detection task by pressing one of two levers when a centrally-located signal occurs (Bushnell & Strupp, 2009). This is functionally similar to the vigilance tasks used for humans because it requires the sustained deployment of executive attention to monitor for the signal and provides comparable parameters of rate of error and reaction time.

A key challenge for measuring changes in attention is that the task used in measurement might itself resolve the antecedents of boredom. To demonstrate, another paradigm used to assess attention in animals is the five-choice serial reaction time task (5CSRTT), in which the animal is trained to respond to the illumination of a randomly selected hole out of five choices (Stolerman et al., 2000). Compared to the simpler signal detection task, the 5CSRTT task is less restrictive, as the animal has multiple options giving them greater control over their response. Thus, in the context of boredom research, executive attention may only be measurable in situations where the measurement does not interfere with the antecedents of boredom (i.e. monotonous and/or restrictive task paradigms), limiting its applicability.

In contrast, the alerting and orienting attention networks can be assessed in the home environment. The function of the alerting attention network is indicated by the degree of sensitivity to incoming stimuli, which may be measured in humans via behavioural reaction time in specific task performance paradigms such as the Attention Network Test (Posner, 2008). In animals, behavioural reaction time can be assessed through behaviours that indicate a change in the orientation of attention. For example, the direction of attentional focus may be identified through the physical orientation of the body, gaze, or ears, and movements (Wemelsfelder, 1993b). Reaction time can therefore be measured as the time taken to orient towards a different focal point at the onset of an unexpected stimulus (Rochais et al., 2014, 2017). Such changes in orientation also reflect the function of the orienting attention network, which filters out distractions (Posner, 2016). Thus, reaction time measures would be expected to conflate the functions of alerting and orienting attention networks, but nonetheless provide a measure of attention that can be assessed in the home environment (see section 4.3 below) without the need for specific task paradigms. Orienting attention processes could also be assessed by a measure of distractibility, such as the rate of changes in behavioural orientation over time. During boredom, reaction times would be expected to slow down (due to declining attention in the alerting network) and distractibility would be expected to increase (due to disruption in the orienting network).

3.1.3. Cognitive load

In humans, cognitive load is usually assessed through self-report of perceived mental effort and task difficulty (Ouwehand et al., 2021). Like the other cognitive correlates of boredom, cognitive load cannot be directly assessed in animals. In particular, there are currently no identified measures of cognitive *underload* in animals. Similarly to alerting and executive attention, observable indicators may be evaluated during operant tasks used to stimulate cognitive *overload,* but this requires an assumption about the conditions that will lead to overload in animals which cannot be confirmed through self-report as it can in humans. One such task is the n-back task adapted for rodents, in which the animal is sequentially presented with levers in five different locations and then required to press either the last (1-back) or second-last (2-back) lever in the sequence (Ko & Evenden, 2009). The 2-back condition is assumed to represent higher cognitive load as the animal must recall the last two lever locations rather than just the last one. Cognitive overload is recognised by reduced accuracy, expressed as a ratio of total correct responses to total trials completed.

Measuring cognitive load in the context of boredom research is subject to the same challenge as attention measures; it requires a method that does not interfere with the antecedents of boredom presented. The currently available paradigms for assessing cognitive load in animals all involve regular changes in cues (disrupting monotony) and multiple response options (disrupting restriction), so do not appear suitable for use in this context.

3.1.4. Time perception

In humans, boredom is commonly associated with changes in the perception of time (Chapter 2, section 2.3.4). Animals may experience time differently to humans; it has been proposed that other animals don't have a conceptual understanding of the passage of time but experience it as a passing of regular cues such as changes in light, temperature or scent (Abraham et al., 2013; Horowitz, 2010; Rehn & Keeling, 2011). Nonetheless, relative changes in the perception of time can be assessed in individual animals. Burn (2017) reviewed three potential methods for assessing time perception in animals: interval timing paradigms, duration reproduction paradigms, and clock-watching behaviour.

Interval timing paradigms (e.g. Taylor et al., 2002) involve training an animal to expect a specific event after a predictable duration, and to perform a distinctive behaviour that indicates that they are anticipating the event, while in duration reproduction paradigms the animal is trained to perform two distinct behaviours in response to different durations of a stimulus (e.g. a white noise signal, Meck, 1983; an image on a screen, Liu et al., 2023). If the stimulus is short in duration, the animal performs behaviour A while if it is long, they perform behaviour B. The animal is then given a stimulus of intermediate duration. Paradigms focussed on judgement of duration are challenging to interpret in the context of boredom, particularly because, in humans, there is no consistent relationship between judgements of duration and subjective time perception (Wearden, 2015). Nonetheless, when conditions are manipulated to increase the likelihood of boredom occurring, it is predicted that animals should overestimate duration (Danckert & Allman, 2005).

In addition, Burn (2017) proposed the development of a 'clock-watching' paradigm, in which an animal is trained to recognise a simple visual clock (such as a countdown slider) as a predictive cue for the onset of a desired event. Behaviour related to monitoring the clock would be expected to occur more frequently under a manipulation expected to increase the likelihood of boredom, as the animal has more attentional resources to allocate towards tracking the available time cues.

Several methods are available for measuring time perception, but further exploration is needed to clarify the interpretation of judgements of duration. Clock-watching may provide a more straightforward assessment and could feasibly be assessed without resolving the antecedents of boredom.

3.2. Meaning

In humans, the construct of meaning is particularly important to the experience of boredom, and theory suggests that it plays an important role in shaping the behavioural outcomes of boredom (e.g. high meaning promotes goal perseverance while low meaning promotes goal switching) (Chapter 2, section 2.4). Understanding the role of meaning in the lives of animals is therefore an important challenge for understanding their potential for, and responses to, boredom.

A social construct is an idea that exists on the basis of socially shared interpretive and representational processes (Maines, 2000). In other words, an idea is constructed when conceptual knowledge is shared among individuals. In humans, language is an important part of this process. While animals are thought to have conceptual knowledge, it is not yet clear whether that knowledge can be shared (Bliss-Moreau, 2017). Therefore, to the best of current understanding, animals are not thought to have constructs that are influenced by shared social and cultural understandings. Some highly social species do demonstrate social learning that is based in observations of behaviour in specific contexts (e.g. through imitation; Bates & Byrne, 2010), but as far as is known they do not share constructed knowledge such as values or life meaning. This presents an inherent limitation to the discussion, as any concept of meaning in animals will not directly reflect meaning as it is understood in humans. Nonetheless, meaning can be thought of as a kind of motivational process and further exploration of the concept in animals may provide an approach that contributes to the understanding of boredom in animals.

One way to conceptualise whether a task is meaningful to an animal is to consider whether that task contributes to its survival, either directly (e.g. by obtaining food or other survival-critical resources) or through the development of skills that are survival-enhancing. Špinka (2019) introduces the concepts of action-driven and competence-building agency. Action-driven agency refers to the performance of activities that serve to achieve immediate outcomes while competence-building agency refers to activities that facilitate knowledge- or skill-enhancement. Both categories of activity involve engagement in tasks that contribute to overall fitness, meaning that motivational drives towards such tasks are likely to be strongly conserved across generations.

According to this conception, the meaning of a task could be operationalised as the extent to which performance of the task contributes to survival or survival-related competence for a given taxon; this might also be framed as the ecological relevance of the task (e.g. Clubb & Mason, 2004) and be measured, or at least characterized, in studies of boredom. In captive and domesticated species, measuring meaning in this way would require consideration of the knowledge and skills that have been adaptive for that species in their phylogenetic history. This idea is already in common use in animal sciences; it is demonstrated that animals are driven to perform some highly motivated, species-specific behaviours even in the absence of appropriate opportunities (e.g. rooting and maternal nesting behaviours in pigs; Jensen & Pedersen, 2010; Jensen, 1986; Newberry & Wood-Gush, 1988; Wischner et al., 2009).

3.3. Environmental antecedents

The key antecedents of boredom in humans are monotony and restriction, which may also be characterized to provide potential environment-based indicators of boredom in animals. These kinds of indicators represent a further step away from the subjective state compared to subject-based indicators, so are less preferred and more challenging to validate (Beausoleil & Mellor, 2017) and to defend against claims of circular reasoning or anthropomorphic argument.

The term monotony is not used consistently across disciplines. In humans, monotony is most often conceptualised as a high degree of repetition in discrete tasks. In this sense, monotony refers to a lack of change over time. While some animals may be required to perform tasks repetitively (e.g. during training), in animal sciences the term monotony seems to be used more commonly in reference to the lack of complexity in barren spaces (Burn, 2017). In this context, the term "barren" is used to describe a space with limited manipulable objects or interactive structures, such as an empty cage (e.g. Bak & Malmkvist, 2020; Bolhuis et al., 2005). Such spaces are regularly compared to more complex spaces that include manipulable objects and/or interactive structures, often called "enriched" environments. For example, rats may be housed in barren cages that contain only food and water, or enriched cages that also contain items such as bedding material, tunnels, wooden chews, and climbing ladders (Simpson & Kelly, 2011).

Although complexity is challenging to measure *per se*, it can be characterised by the provision of manipulable and interactive objects or structures in an environment (described as item complexity by Pritchett-Corning, 2019). The items used to increase complexity differ across species and situations, but in general a complex environment contains more objects and structures, contrasting with a barren environment which contains only resources necessary for survival (i.e. food and water).

Restriction can be characterised by the abundance of goal-oriented behaviours (i.e. opportunities to exert control; Englund, 2023) facilitated by the environment. In a barren environment, the only goal-oriented behaviours available might be eating, drinking, and self-directed behaviours such as scratching and grooming. In contrast, a complex environment might also provide opportunities for behaviours like nesting, climbing, and non-nutritive chewing. This provides an objective characterisation of restriction, but the related concept of judgement of control depends on how the animal perceives the affordances of the items available, that is, whether the items facilitate behaviours that they are motivated to perform. Judgement of control is discussed further in section 4.3 below.

By these characterisations, environmental complexity and restriction are not independent. In a barren environment, there is little complexity and correspondingly few opportunities to exert control (i.e. high degree of restriction). As environmental complexity increases, animals are more able to exert control through their choice of interactions with features of the environment and may even further increase the complexity through their actions (e.g. by relocating or breaking objects). Thus, in this Chapter the environmental antecedents of boredom are discussed together as "environmental complexity" (section 4.2). The relationship between change over time (another conception of monotony) and restriction, including situations where these factors can be manipulated independently, is further discussed in Chapter 4.

3.4. Behavioural outcomes

Until the physiological correlates of boredom are better understood, the behavioural outcomes provide the most promising indicators for investigating boredom in animals. These include goal-switching, goal-perseverance and various behaviours that do not seem to be goal-related. Many behavioural outcomes observed in humans are measurable in animals; however, their expression is so dependent on environmental antecedents, judgement of control and meaning that it isn't possible to discuss them separately. Therefore, I will address their applicability in section 4.3, after discussing the manipulable correlates of boredom below.

3.5. Revised framework for investigating animal boredom

All four categories of boredom-related factors (environmental antecedents, physiological and cognitive features, social and cultural features, and behavioural outcomes) provide some potential indicators that can be measured in animals (Figure 5). For some of these indicators, further understanding of their roles in human boredom is needed to identify the direction of change that would be expected during the experience, but nonetheless they can be measured in animals to determine whether a change occurs during exposure to boredom antecedents.

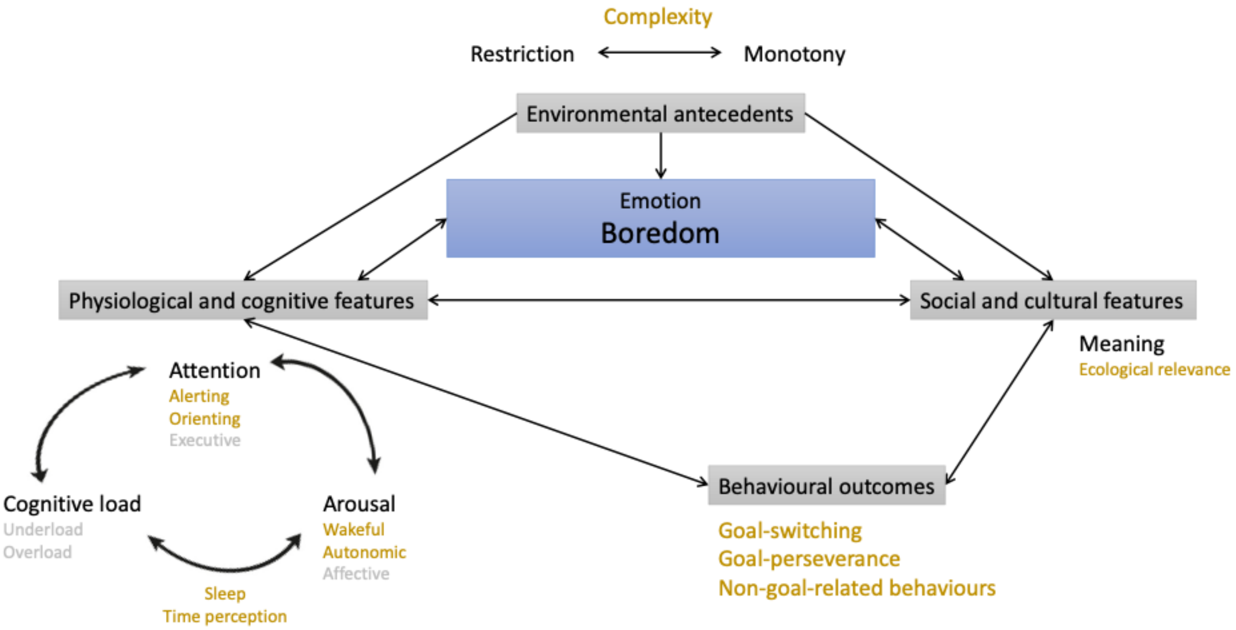

Figure 5. Proposed framework outlining the correlates of boredom as identified in humans, adapted to show which correlates and outcomes are currently applicable to investigation of boredom in animals. Items in yellow represent measurable or observable outcomes that may be used as indicators to explore a boredom-like state in animals. Items in grey are not currently observable or measurable in animals so cannot be used to investigate emotional experiences.

4. Correlates of human boredom that are manipulable in animal research and evidence of expected outcomes

While the previous section discussed the measurement of boredom correlates, this section examines which of these can be manipulated in animals. In humans, boredom apparently occurs when the cognitive resources available to the individual do not align with the demands of the environment (Chapter 2, section 2.3.3). Thus, the key to manipulating correlates of boredom is to alter one of these two factors. Evidence from animal research of associated changes in the measurable physiological and cognitive correlates of boredom identified above is described in this section, but overall little work has been done that both manipulates at least one correlate of boredom (without resolving the antecedents of boredom, as in behavioural tasks described above) and measures one of the potential indicators discussed above. Most of the studies that meet these criteria measure aspects of behaviour. Due to the complex interactions between factors that are expected to influence the behavioural outcomes, including the individual's availability of cognitive resources relative to demand, judgement of control, and goal meaning, evidence related to behavioural responses is considered separately in section 4.3.

Until the concept of meaning for animals is better understood and operationalised, it cannot be actively manipulated, so meaning is not discussed in this section.

4.1. Manipulation of cognitive resources

Arousal, attention, and working memory are closely interacting cognitive processes that often have dependent effects on each other when one is manipulated. As wakeful arousal declines so too does the performance of attention and working memory (Alhola & Polo-Kantola, 2007). In turn, autonomic arousal influences wakeful arousal in some circumstances; when heart rate increases due to physical activity, wakefulness is also increased (Bonnet & Arand, 1999), and substances such as caffeine increase both types of arousal (Li et al., 2023).

Wakeful arousal can be manipulated through environmental conditions such as changes in body temperature (Fronczek et al., 2008), or testing during different stages of the light/dark cycle (Wright et al., 2012), but the most promising manipulation for use in boredom research is sleep deprivation. The ability to maintain wakefulness declines over time spent awake (Bonnet & Arand, 1999), and sleep deprivation has also been shown to impair cognitive performance (Alhola & Polo-Kantola, 2007). In addition, the effects of autonomic arousal (increased through physical activity) are increasingly short-lived as time spent awake increases (Bonnet & Arand, 1999). This means that sleep deprivation may be particularly useful for manipulating the availability of cognitive resources in animals that tend to be more active (and therefore prone to spontaneous increases in autonomic arousal).

Sleep deprivation paradigms have been developed for various animal species including cattle (Kull et al., 2019), rodents (Endo et al., 1997; Franken et al., 1991), and pigeons (Newman et al., 2009), and impairments in attention (Córdova et al., 2006) and working memory (Hagewoud et al., 2010) have been demonstrated. Where EEG recordings are utilised, studies usually focus on sleep during recovery, so measures relevant to boredom such as EEG activity during wakefulness are typically not reported. Similarly, where behavioural measures are utilised, they tend to focus on anxiety- and fear-responses (reviewed by Pires et al., 2016) and are therefore not informative for understanding boredom.

The availability of cognitive resources could also be manipulated through task duration. The availability of attentional and working memory resources depletes over time when those resources are deployed (Chen et al., 2018; Smit et al., 2004). Correspondingly, cognitively engaging tasks with long durations would be expected to deplete cognitive resources over time, increasing the likelihood of boredom occurring as a function of time-on-task. Supporting this, during a vigilance task of 30 minutes duration, reaction time increases over time in rats (Oonk et al., 2015).

Time perception has been manipulated in rats using the administration of methamphetamine (faster perception) and haloperidol (slower perception) (Meck, 1983). Attention and working memory are also involved in time perception (Matthews & Meck, 2016), so controlling these features may also lead to an indirect manipulation of time perception. Time perception can also be manipulated through exposure to emotional facial expressions in Rhesus macaques (*Macaca mulatta*) (Liu et al., 2023). However, to date, studies that manipulate time perception in animals have not assessed effects on other proposed boredom indicators such as distractibility, blink rate, or behavioural outcomes (other than performance on the time perception task).

Several approaches to manipulating the availability of cognitive resources in animals may be useful for further research, but sleep deprivation is the most readily applicable as paradigms have already been developed for several species.

4.2. Manipulation of environmental demand on cognitive resources

Manipulating the demand on cognitive resources can be accomplished through changes in the complexity of the environment. A more complex environment provides more opportunities for the engagement of cognitive resources, while a less complex (i.e. barren and restrictive) environment leaves those resources underutilised. Manipulating environmental complexity involves adding or removing manipulable objects and interactive structures in the environment. This is often done in the home environment to investigate how complexity influences outcomes related to physiological function (e.g. Doulames et al., 2014; Ohline & Abraham, 2019), neuroanatomical changes (e.g. van Praag et al., 2000), or anxiety and fear

(Lopes et al., 2017). Demand on cognitive resources might also be increased through a higher rate of change over time, discussed further in the next chapter.

Manipulating the complexity of an environment has been demonstrated to influence some of the measurable cognitive correlates of boredom identified in the previous section. For example, rats moved to a more complex environment for three hours spent more time in a state of active wakefulness (assessed via EEG) compared to those left in a barren environment (Santos et al., 2023). This is consistent with the expectation that a more complex environment provides more opportunities for engaging cognitive resources, and suggests that animals in complex environments are less likely to experience boredom (but see Chapter 4 for a discussion of the effects of familiarity).

4.3. Behavioural outcomes

The most promising indicators of boredom in animals are behavioural outcomes. Based on the discussion of boredom-related behaviours in Chapter 2 (section 2.6), there are three distinct categories of behaviour that animals would be expected to perform during exposure to boredom antecedents: goal-switching and goal-perseverance are both goal-directed behavioural strategies that aim to alleviate boredom, and a range of other behaviours are associated with boredom in humans but do not seem to be goal-related; such behaviours may be expected to occur when goal-switching or -perseverance strategies are unsuccessful, but further investigation is required to substantiate this idea. In humans, the expected behavioural outcomes in a given situation depend on three key factors: the individual's availability of cognitive resources relative to demand, judgement of control, and goal meaning (Figure 6). These factors may also change over time, leading to patterns of behaviour that reflect attempts at different strategies (Chapter 2, section 3.3). This model is useful for predicting and interpreting the behavioural responses of animals exposed to different combinations of boredom antecedents.

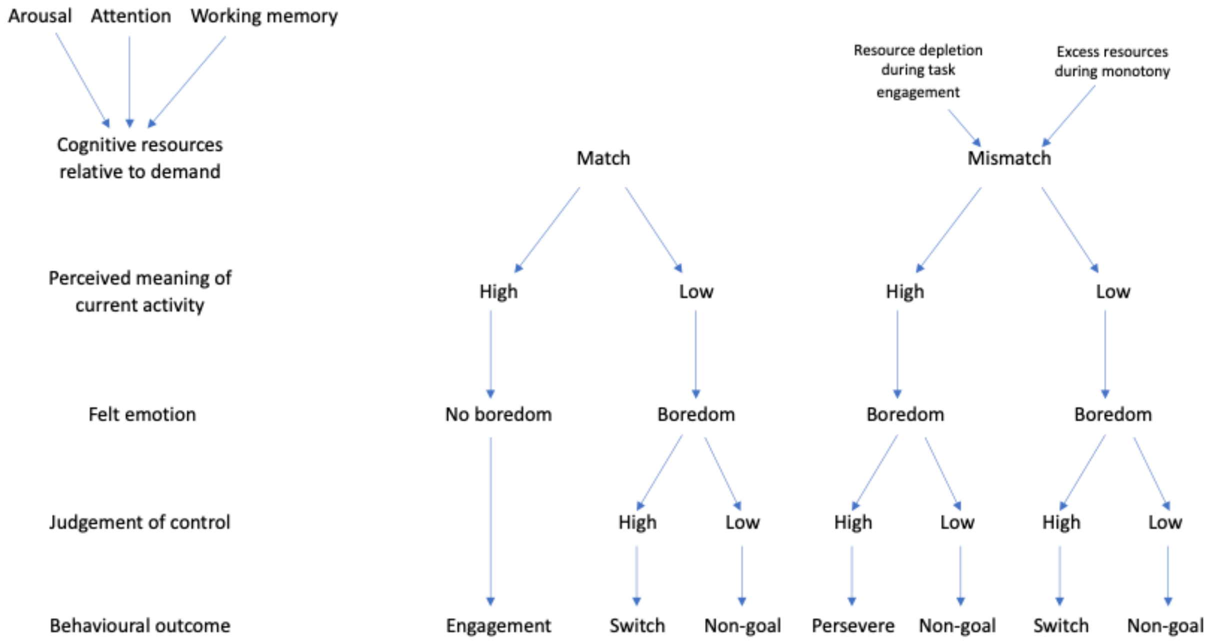

Figure 6. Schematic diagram showing the relationships expected to influence behavioural responses to different combinations of boredom antecedents, based on human research. Attempts at the three behavioural strategies may feedback at different levels by influencing the availability of cognitive resources, the perceived meaning of the activity, or the animal's judgement of control. Switch refers to goal-switching behaviours and persevere refers to goal-perseverance behaviours. Engagement reflects the ability to adequately engage in a goal-directed task without experiencing boredom, and non-goal refers to non-goal-related behaviours; those that are associated with boredom but do not contribute to either goal-switching or goal-perseverance.

In the following section, this model is used to interpret findings from existing research in terms of goal-switching, goal-perseverance, and non-goal-related behaviours. According to the model, boredom occurs when there is a mismatch between cognitive resource availability and demand, or when a task is perceived to be low in meaning. The behavioural strategy employed then depends on the perceived meaning and judgement of control; low meaning prompts goal-switching when control is adequate and non-goal-related behaviour when control is restricted, while high meaning prompts goal-perseverance when control is adequate and other behaviours when control is restricted. Importantly, the model predicts that low judgement of control will always lead to non-goal-related behaviours. This suggests that animals housed in barren environments (i.e. low complexity and low control) would only be expected to exhibit non-goal-related behaviours unless provided with an opportunity to exert control through goal-directed behaviour (i.e. engaged goal pursuit, goal-switching or goal-perseverance). For animals in complex environments, even if their cognitive resources match the demands of the environment, boredom-related behaviours would be expected to occur if there are no meaningful tasks available; goal-switching if the animal perceives adequate control or non-goal-related behaviours if it is restricted by some factor other than the complexity of the environment (e.g. physical restraint).

A range of different methods have been developed to assess the effects of manipulating environmental complexity on animals' behavioural responses. Many of these methods involve the use of behavioural tests in which animals that have been housed in barren or complex environments are individually removed from those environments and assessed in different conditions designed to create anxiety or fear (e.g. open field test, Gould et al., 2009; light/dark test, Arrant et al., 2013), or assess responses to novelty (e.g. novel object test, Dalmau et al., 2009; Visser et al., 2002). However, the value of these kinds of tests for understanding the effects of environmental complexity on behavioural outcomes of boredom is limited. Placing an animal in an unfamiliar environment resolves the antecedents of boredom that are present in the home environment by providing novel opportunities for exploration and interaction with the environment (increasing cognitive demand). If the animal was left in the new environment for an extended time then they may become familiar enough with it for boredom to occur (see Chapter 4, section 3.2), but given that such tests are designed to assess fear-related responses and are performed in isolation from social companions, the experience of fear or anxiety is likely to delay the occurrence of boredom (also see discussion of novelty-seeking responses by Mieske et al., 2022). Thus, assessments that occur outside of the home environment are not further discussed here.

Methods that observe the responses of animals in their home cage are more informative for boredom research because they do not disrupt the animals or interfere with the antecedents of boredom. The frequency and duration of specific behaviours, predicted by the model in Figure 6, exhibited by animals can be compared between those housed in a barren (i.e. low complexity, high restriction) environment and those held in a more complex environment (section 4.3.3). Another method that assesses responses in the home cage does disrupt the animals, by adding an unfamiliar object and observing their responses. Novel object tests provide an additional element of complexity and opportunity for control (reducing restriction) in an otherwise very familiar environment. Animals that experience boredom more often or intensely in that environment would be expected to spend more time engaged with the novel object, indicating that they successfully switched goals when the opportunity was provided (section 4.3.1).

The timeframe over which animals are subjected to barrenness is very different to the timeframes that boredom is considered on in human research. Human studies induce boredom across minutes to hours, while studies of environmental complexity tend to use timeframes covering weeks to months of continuous exposure to monotony and restriction (e.g. Abou-Ismail & Mendl, 2016; Meagher & Mason, 2012). Chronic exposure to boredom antecedents is rarely studied in humans but is highly relevant to many kinds of animals. However, this means that little is known about how the emotion and associated manifestations might be expected to change over extended time periods. As the following sections highlight, this introduces an additional challenge to interpreting current animal research in the context of boredom.

4.3.1. Goal-switching

According to the model outlined in Figure 6, if boredom occurs whilst engaged in a task that is low in meaning, and the individual perceives adequate control, they will disengage from that task and seek an alternative (i.e. goal switch). In such cases, exploratory behaviour and sensation-seeking behaviour may provide useful indicators of boredom. Exploratory behaviour should be interpreted with caution as it may be innately rewarding (Hintze & Yee, 2023) and other feelings, such as curiosity or fear, may be involved depending on the situation (e.g. when investigating predators; FitzGibbon, 1994). An animal that is actively exploring its environment may have successfully mitigated boredom by changing goals so may not be experiencing boredom at that time. Thus, exploratory behaviour could be an indicator of recent boredom stimulating a change in behaviour but is not necessarily a sign that an animal is still actively experiencing boredom.

On the other hand, sensation-seeking behaviour, and particularly repeated interactions with aversive stimuli, also occurs *during* boredom in humans (Chapter 2, section 2.6.1) and therefore is a useful indicator that an animal is feeling bored in the current moment. In the context of the model presented above, sensation-seeking (i.e. interaction with normally low-value or aversive stimuli that endures beyond initial information-gathering) can be interpreted as a failure to switch goals (i.e. continue exploring after gathering adequate information) due to low perceived control. In other words, the animal continues to seek sensory stimulation because it does not perceive a better option for engaging excess cognitive resources in its environment. This suggests that sensation-seeking could instead be framed as a non-goal-related behaviour.

The distinction between exploration and sensation-seeking is not always clear cut. When gathering information about complex, changing stimuli such as conspecifics or predators, exploration may take a long time or involve repeated approaches (e.g. FitzGibbon, 1994). Despite this, evidence from home environment novel object tests supports the idea that animals housed in barren conditions show behaviour consistent with switching goals when they are given the opportunity (i.e. when they perceive adequate control), followed by non-goal-related behaviour (i.e. sensation-seeking) over time. For example, pigs housed in barren pens spent more time interacting with a novel object placed in their pen compared to pigs housed in pens made more complex through the addition of manipulable substrates (Wemelsfelder et al., 2000). One interpretation is that the barren-housed animals continued to interact with the object beyond the time necessary for information-gathering. Further supporting this idea, when mink were housed in barren cages over a period of months, they were faster to approach and interacted more with aversive stimuli during a novel object test compared to those housed in a more complex environment (Meagher & Mason, 2012). This finding was repeated in a replicate study (Meagher et al., 2017), and mink in barren housing also spent more time oriented towards aversive stimuli compared to mink in enriched housing.

Overall, the available evidence suggests that when environmental demands on cognitive resources are reduced due to low environmental complexity, animals perform behaviours indicative of goal-switching when given the opportunity.

4.3.2. Goal perseverance

In contrast to exploration and goal-switching, if an animal becomes bored whilst engaged in a meaningful task (for example due to the depletion of cognitive resources and thus resource-demand mismatching), then the meaning and attentional components (MAC) model posits that the animal will attempt to regulate its environment and/or cognitive resources to mitigate that feeling (Westgate & Wilson, 2018), provided that it perceives itself as having adequate control to do so. Behaviours indicative of goal perseverance are those that lead to re-engagement in the task following this kind of regulation. For example, an animal might disengage from the task and consume food or water (cognitive regulation) or chase away distracting conspecifics (environmental regulation) before re-engaging. Thus, goal perseverance is not recognisable from discrete behaviours, but from patterns of behaviour over time.

Goal perseverance is unlikely to be observed in animals housed in barren environments due to the limited availability of goal-directed behaviour (high restriction/low perceived control). Rather, such behaviours would be expected to occur in more complex environments when animals engage with meaningful tasks and perceive that they have more control, particularly as cognitive resources become depleted over time. Such tasks might be framed as cognitive enrichment (e.g. Clark et al., 2019). However, studies investigating the effects of cognitive enrichment on animals often do not monitor interactions with the provided object or other behaviours exhibited in its presence that would represent perseverance – rather, they tend to leave the object with the animal for a set period of time then assess the animals' performance on tests related to cognitive performance (e.g. Milgram et al., 2005) or exploration (e.g. Oesterwind et al., 2016; Zebunke et al., 2013).

Where the behaviour of animals with cognitive enrichment is more closely monitored, the results are generally presented as differences in total time spent engaged in various behaviours (e.g. Fagot et al., 2014; Wagner et al., 2016; Whitehouse et al., 2013) or as the proportion of overall time spent on various behaviours (i.e. an activity budget; Yamanashi & Hayashi, 2011). This is challenging to interpret in the context of boredom, because time spent engaging in apparently unrelated behaviours such as eating, drinking, sleeping, or interacting with conspecifics could represent disengagement from the task (i.e. goal-switching, if it is perceived to have low meaning) or attempts to persevere by regulating the self (e.g. support cognitive resources through eating, drinking, or sleeping) or the environment (e.g. reduce distraction through chasing away nearby animals) before re-engaging with the task (if it has high meaning). Both behavioural strategies could indicate attempts to mitigate boredom but can't be understood when data are collapsed.

Importantly, spending more time overall engaged with the task does not necessarily indicate that the animal is not bored; the animal may instead find the task meaningful but need to intermittently regulate its cognitive resources by performing other behaviours, in order to alleviate boredom and allow re-engagement and perseverance. Thus, a more informative measure in this context would be the length of bouts spent on-task; animals that stay engaged for extended blocks of time would be less likely to be bored (i.e. engaged) compared to those that exhibit more frequent, shorter bouts (i.e. persevering), even if the total amount of time spent on the task is equal.

Experimental design may also impede the observation of goal perseverance. For example, when apes housed in complex environments were provided with an opportunity to perform a task that required the engagement of attention and working memory (and therefore could be expected to deplete cognitive resources over time, indicating a need for perseverance behaviours), this opportunity was removed if they stopped participating for over three minutes (Wagner et al., 2016). This precluded observation of any goal perseverance behaviours and demonstrates a need for the assessment of broader patterns of behavioural change over time, allowing for repeated disengagement and re-engagement with a task to understand the potential for boredom in such situations.

Motor patterns such as fidgeting are also related to goal perseverance as they may reflect attempts to enhance cognitive resources through increasing autonomic arousal, particularly where the animal is restricted from performing other behaviours related to goal perseverance. For example, when primates were provided with cognitively engaging tasks they demonstrated self-directed behaviours similar to fidgeting in humans, such as scratching, rubbing, and stroking their faces (Padrell et al., 2022). Although the time-course of these kinds of behaviours has not yet been characterised, they were more frequently expressed when task difficulty was higher (Yamanashi & Matsuzawa, 2010 described by Clark, 2017), suggesting that they reflect attempts to support cognitive function by increasing autonomic arousal, which aligns with the proposed function of fidgeting during boredom in humans. Behaviours related to fidgeting might also be characterised as non-goal-related behaviours (see discussion of ARBs below).

4.3.3. Non-goal-related behaviours

For many animals in restricted environments, it may not be possible to mitigate boredom through behavioural action. According to the model, whenever the animal judges its control to be low, it would be expected to exhibit other behaviours that are not associated with goal-pursuit, -switching, or -perseverance, regardless of the perceived meaning of any tasks available. Thus, in barren environments, which have both low complexity (resource-demand mismatch) and high restriction (low perceived control), a higher proportion of non-goal-related behaviours would be expected and may be particularly important as indicators of boredom. Such behaviours may also follow attempts at goal-switching in a cyclical manner (see Chapter 1, section 3.3).

In animal welfare science, boredom is regularly used to explain the development of abnormal repetitive behaviours (ARB) (e.g. Burn, 2017; Meagher, 2019; Poirier & Bateson, 2017; Wemelsfelder, 1993b) and they may represent a form of non-goal-related behaviour. ARBs are only characterised in captive wild and domesticated animals, so they are often associated with the restriction that is inherent to most management systems (Lewis et al., 2006; Ryan, 2017). Stereotypic behaviours are a type of ARB that appear to be unrelated to a specific goal (Mason & Latham, 2004), so they are particularly relevant to animals housed in barren conditions as options for goal-switching or perseverance are unavailable. This also differentiates ARBs from fidgeting behaviours, as fidgeting (characterised here as a goal-perseverance behaviour) would be expected to occur during goal-directed activity (i.e. whilst attempting to stay engaged in a task). Stereotypic behaviours are claimed to be closely associated with chronic inescapable boredom in animals (e.g. Wemelsfelder, 1993). Examples of stereotypic behaviours include pacing (Quirke et al., 2012), repetitive head movements (Dallaire et al., 2012), and licking non-nutritive objects (Fernandez et al., 2008).

Comparing the occurrence of ARBs between humans (where their correlation with reported boredom can be assessed) and animals is challenging because of an important contextual difference. In humans, ARBs such as tapping and bouncing occur when subjects are placed in restrictive conditions for a short time period, such as a five-minute wait (Ryan, 2017). These conditions impose a degree of restriction that is not regularly experienced by humans in our day-to-day lives, limiting opportunities for goal-oriented behaviours. In contrast, when macaques were left in an analogous five-minute waiting paradigm, they did not show a change in the frequency of ARBs such as pacing, hair-pulling, and self-stroking compared to baseline observations (Ryan, 2017). This is not because the wait failed to induce the performance of ARBs, but because the animals experienced a similar degree of restriction across their typical day and regularly performed ARBs outside of the waiting paradigm.

This could be seen as support for the association between stereotypic behaviours and chronic, inescapable boredom. However, these behaviours do not seem to occur consistently in animals kept in barren conditions. In some studies, ARBs occur less frequently in animals kept in complex environments (e.g. Kitchen & Martin, 1996; Meagher et al., 2017; Powell et al., 2000; Turner et al., 2003) while in others no significant difference is observed (e.g. Abou-Ismail et al., 2010; Spring et al., 1997). It is possible that, where no difference was observed, the animals expressed other non-goal-related behaviours or that other behavioural strategies were facilitated by the environment.

Individual factors other than the current environment influence the development of ARBs. Some identified factors include sex, age, and social conditions (e.g. social animals housed alone or with conspecifics) (Gottlieb et al., 2013). Factors related to personality also seem to be associated with the performance of ARBs (Ijichi et al., 2013). For example, animals that tend to respond to novel or threatening stimuli with higher behavioural activity also exhibit higher rates of ARB (Gottlieb et al., 2013; Joshi & Pillay, 2016). Accordingly, some animals are more prone to developing ARBs while others don't seem to perform such behaviours under comparable conditions. This means that ARBs on their own are not useful as an indicator of state boredom because they are prone to false negatives. Nonetheless, they might relate more reliably to a trait comparable to boredom proneness or sensation-seeking in humans. Once methods for identifying state boredom in animals are more established, ARBs might prove useful for examining the effects of trait boredom.

Sleep-related behaviours may also be associated with boredom in humans (Chapter 2, section 2.6.3), but they are challenging to interpret because they would be expected to change over time. In some short-term situations, such as during transport or temporary confinement, animals may perform fatigue-related behaviours similar to those described in humans such as yawning and sighing (Burn, 2017; Fureix et al., 2011). According to the understanding of boredom in humans discussed in Chapter 2, these behaviours would be expected to decrease in frequency under long-term barrenness due to an increase in the frequency of sleeping bouts during boredom, leading to reduced tiredness even though boredom is not alleviated.

In contrast to this idea, animals housed in barren environments seem to sleep less than those in more complex environments (e.g. Abou-Ismail, 2011; Abou-Ismail et al., 2010; van Gool & Mirmiran, 1986). This supports the idea that these animals are less tired but indicates a different cause for this outcome. An alternative explanation is that animals in barren environments have fewer opportunities to utilise both cognitive and physical resources through goal-directed action and exercise, leading to a lower need for sleep. Supporting this, evidence shows that activity levels are often higher in complex environments compared to barren ones (e.g. Jacobs et al., 2023), although the more frequent performance of ARBs in barren-housed animals may obscure this effect (Mieske et al., 2022). In brief, sleep-related behaviours such as yawning are potentially more informative as indicators of acute boredom but there is an overall need to characterise how patterns of sleep and related behaviours change over time in barren versus complex conditions.

Following from the above, animals do not seem to replace goal-directed behaviour with sleep under barren conditions, but it has been suggested that they may instead replace it with awake inactivity (Burn, 2017). However, awake inactivity does not occur reliably in barren conditions with some studies reporting an increase in frequency, total time spent, or number of animals performing (e.g. Abou-Ismail, 2011; Hintze et al., 2020; Schmitt et al., 2024), one demonstrating a decrease in total time spent (Polanco et al., 2021), and others not finding a significant association (e.g. Abou-Ismail et al., 2010; Spring et al., 1997). Early theoretical accounts of animal boredom suggest that inescapable boredom first leads to fatigue and sleep, but when the subject has fulfilled their need for sleep they will become restless (Wemelsfelder, 1993a). This seems to agree with the temporal account of boredom discussed in Chapter 2, which predicts cycles of different behaviours over time that reflect attempts at goal-switching followed by a return to non-goal-related behaviours when unsuccessful and may explain the inconsistent association of awake inactivity with antecedents of boredom. Bored animals with low perceived control (i.e. in barren, restrictive environments) may lie awake but inactive in between bouts of restlessness when they are not able to sleep. As awake inactivity is usually assessed with intermittent sampling (e.g. Meagher et al., 2017; Polanco et al., 2021; Schmitt et al., 2024; Webb et al., 2017), this wider behavioural pattern may have been obscured in past studies. Future research could use continuous monitoring to assess whether such a pattern occurs more reliably during exposure to antecedents of boredom compared to awake inactivity alone.

Another behaviour associated with boredom in humans is mind-wandering. Animals are not thought to be capable of mind-wandering *per se*, but some animals (namely rats) are thought to be capable of replaying spatial detail from past events and imagining spatial detail of future events, called hippocampal replay (Karlsson & Frank, 2009) or mental time travel (Corballis, 2013). Mental time travel may occur during periods of inactivity (Karlsson & Frank, 2009), similarly to mind-wandering during boredom. It is measured via implanted microdrive arrays that capture the electrical activity of populations of neurons in the brain (i.e. local field potential), and therefore can be assessed remotely, without requiring physical restraint. Future research could therefore assess the prevalence of mental time travel during exposure to boredom antecedents such as barren or restrictive home environments.

5. General discussion and conclusions

Most of the correlates related to boredom in humans can be measured directly or indirectly in animals, although care should be taken when assessing cognitive features with task-based paradigms to ensure that the task design does not resolve the antecedents of boredom. The concept of meaning requires operationalisation for animals, and one potential approach to this was presented that focusses on the ecological relevance of discrete tasks.

There are two key approaches to manipulating the correlates of boredom, involving the manipulation of either the availability of cognitive resources (manipulation of the subject) or the environmental demand on those resources (manipulation of the environment). Although sleep deprivation may provide a promising manipulation of cognitive resources for future use, most existing literature that includes the measurable correlates of boredom manipulates the complexity of the environment.

By far most existing research centres around behavioural outcomes. Evidence from novel object tests demonstrates that animals housed in barren environments perform behaviours indicative of goal-switching when given the opportunity. On the other hand, goal perseverance behaviours are challenging to recognise and there is a need for future research to characterise patterns of behaviour during task engagement. In terms of non-goal-related behaviours, interpreting the occurrence of sleep and related behaviours, including awake inactivity, would also be aided by considering wider behavioural patterns. ARBs may be more informative for the future investigation of trait boredom, and mental time travel could be considered similar to mind-wandering in humans so may also be an interesting direction for future research.

A recurring limitation throughout the discussion of behavioural outcomes is that the temporal pattern of responses is not reported. Current knowledge of human boredom does not provide a specific time-course for how boredom responses might develop from the initial exposure to an environmental antecedent, so there is currently no evidence to indicate when responses should be recorded during manipulations. To account for this, animals should ideally be monitored continuously from the time of exposure to a predetermined endpoint, and observed responses should initially be characterised as patterns rather than individual events. These patterns can then be compared to patterns of response seen in humans when these become better understood.

Another challenge in understanding boredom in animals is that there is a difference in the timeframe over which humans and animals are exposed to boredom antecedents. This seems to reflect a difference in the way that boredom is conceptualised in animals. Boredom in humans is most often discussed in reference to a particular task (i.e. the subject is bored *of* a task). In contrast, animal boredom tends to be discussed in a broader sense, referring to the wider situation the subject is in (e.g. Meagher et al., 2017; Meagher & Mason, 2012). However, Wemelsfelder (1993) argues that these situations are similar in two key respects: both provide limited stimuli to engage with (i.e. low environmental complexity), and both involve a high degree of behavioural restriction.

It is currently unclear whether task-based monotony (i.e. a low degree of change in repetitions of a task) is perceived or responded to similarly to a lack of complexity in a space, although the latter may also be called 'monotony' in discussions of animal boredom (e.g. Burn, 2017). In the studies discussed above, the effect of behavioural restriction is the predominant feature, and my model predicts that animals so restricted will show mostly non-goal-related behaviours. Given that some degree of restriction is inherent to animal-keeping, developing a better understanding of the role of change over time may support the development of strategies that can be used to protect and enhance the welfare of animals that are housed in unavoidably restrictive conditions.

To understand how lack of change over time impacts the welfare of animals and whether it relates to boredom outcomes independently of restriction, it is necessary to first examine the ways that animals might be exposed to change and the factors that influence how it is perceived. From there, the ways that animals respond to different presentations of low change can be examined and compared. The next two chapters describe an approach to examining the impacts of change over time on animal welfare.

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Chapter 4, Investigation of the factors influencing whether monotony, relating to change over time, is perceived as an antecedent to boredom

1. Introduction

Animals of many species have evolved to cope with variability in their physical, sensory and social environments. From fluctuations in light, temperature and weather to variation in social groups, food availability, and physical location, animals are well equipped to deal with change. Species that have evolved to fill opportunistic or generalist niches are particularly sensitive to variability as they often survive by exploiting changes in the environment, such as novel food sources, that other species are not able to take advantage of (Bench & Lench, 2013; Burn, 2017).

When animals are kept by humans their environments are highly controlled and the variability of their living conditions is limited. In recent decades, a growing understanding of how environmental features influence the welfare of animals has led to efforts to improve the ways in which we keep them (Bailoo et al., 2018; Olsson & Dahlborn, 2002). The focus of research in this area is how best to add complexity to the lives of animals in human care (environmental, behavioural, or cognitive enrichment; Clark, 2017; Godyń et al., 2019; Wells, 2009). However, there has been less attention paid to the importance of change over time, and there is a distinct lack of research investigating how an *absence* of change impacts animals. In previous research, these two concepts, lack of complexity and absence of change, have both been described as monotony. Monotony as lack of complexity (barrenness) was explored as an environmental antecedent of boredom in animals in the last chapter. For clarity, the term monotony is used hereafter specifically in reference to a low degree of change over time.

In humans, exposure to monotony, defined this way, is an antecedent of boredom. As discussed in Chapter 2, this may be related to the low demand on cognitive resources when conditions become familiar and don't change over time, which seems to prompt an emotional experience that promotes the seeking of opportunities for cognitive engagement. For animals, there is a general expectation that monotony leads to unpleasant mental experiences such as boredom, as it does in humans (Burn, 2017). Should monotony be perceived as aversive, it would be expected that animals would choose to avoid it if given the option (Rushen, 1996). In support of this idea, many domestic and captive wild animals also seem to take opportunities to employ their cognitive resources when such opportunities are available, for example by contrafreeloading – when an animal works for resources such as food even when identical resources are freely available (Inglis et al., 1997). An interpretation of contrafreeloading is that animals may be seeking to increase their cognitive load.

The presence of an aversion response would suggest that forcing the animal to be exposed to that stimulus or environment might lead to negative experiences and compromise its welfare (Kirkden & Pajor, 2006). If this is the case, monotony would represent an animal welfare risk for many millions of animals world-wide. In the conceptual framework developed in Chapters 2 and 3, it is implied that monotony is an antecedent to boredom in animals whenever it is present. However, monotony may not always be perceived and/or may not be perceived as aversive, and various factors are likely to influence this. For species that are adapted to exploit existing resources within their niche (i.e. specialists; Snell-Rood & Steck, 2019), monotony is more likely to indicate success in accessing and exploiting crucial resources and is unlikely to be aversive. For example, koalas (*Phascolarctos cinereus*) only eat leaves from *Eucalyptus* trees, and have a limited ability to adapt to dietary change (such as access to different *Eucalyptus* species) (Blyton et al., 2023). Thus, finding dietary monotony aversive would be maladaptive for koalas as this would motivate them to consume food that they could not efficiently digest, leading to malnutrition. However, koalas may perceive variation in their food that is not apparent to human observers, and thus not respond to conditions that appear to be monotonous from the perspective of humans. There is no practical way to differentiate between an animal that does not perceive a condition as monotonous and one that does perceive monotony but does not find it aversive. The perception of monotony in specific resources is discussed further in section 2.1.2. This demonstrates a need to examine the ways in which animals may be exposed to monotony and the factors that might influence how it is perceived and responded to, to facilitate the systematic investigation of how monotony impacts the welfare of animals.

This chapter investigates which factors influence whether animals perceive monotony (as a lack of change over time) – a prominent environmental antecedent of boredom in humans. A secondary question considered throughout is whether, when monotony is perceived, animals find it aversive. To explore these questions, I first describe three different ways that monotony can be objectively presented and the patterns in which this may occur, then demonstrate how interactions between patterns of monotony and subject-related factors influence whether it is likely to be perceived.

While it is likely that individual factors (i.e. traits and predispositions) also impact how animals respond to monotony (Snell-Rood & Steck, 2019) and consideration of these factors is an important area for future research (Chapter 6), it is outside the scope of this thesis.

2. Objective factors influencing the presentation of monotony

In humans, the term monotony is most often used to describe highly repetitive tasks (task monotony below). But many different features within an animal's long-term environment may or may not change over time, and that change may occur in various patterns, both of which could influence the animal's perception of monotony (section 2.2). This section introduces three types of change that are relevant to understanding the impacts on animals of human-managed environments and patterns in the way that change in these categories may occur.

2.1. Type of change

Change or its absence can be characterised as three different types that are not mutually exclusive but that represent different ways of considering how monotony might be perceived by an animal. These types relate to the potential for monotony in the way animals are actively involved in goal-directed activity (task monotony), the category of resource that might become monotonous (resource monotony) and the animal's social environment (social monotony).

2.1.1. Task monotony

Animals regularly interact with features of their environment, performing voluntary behaviours to pursue goals that they perceive as important. Goal-oriented behaviours have three observable components: the antecedents that cue the behaviour, the behavioural action, and the extrinsic outcomes of that action (Friedman, 2009). For clarity, here I use the term "task" to refer to these three components together – leaving "behaviour" to refer specifically to the action itself. This aligns with the use of the term task in psychology, where it refers to a goal-oriented activity (American Psychological Association, 2018; Gozli, 2019; Chapter 2).

Exposure to task monotony in humans is associated with a range of observable and reported cognitive and behavioural impairments including fatigue (Bier et al., 2019), attention deficits (Thackray, 1981), and impaired task performance (Kiroi & Aslanyan, 2006) as well as reports of unpleasant mental experiences such as boredom (Loukidou et al., 2009). Prevailing theories link these effects to impairments in executive function caused by cognitive underload and subsequent changes in motivational state (Ma et al., 2018; McWilliams & Ward, 2021; Michael, 2011).

Task monotony is relevant to animals in any circumstance that allows for goal-directed behaviour but that places some restriction on the ability of the animal to switch goals, such as situations where only a single task is available. For example, in animal training, goal-switching is often restricted by the trainer, who can control what tasks are available by withholding cues or preventing the animal from responding to available cues. In animal housing systems, goal-switching may be restricted by low environmental complexity e.g., the availability of substrates, manipulable objects, and interactive structures, or by physical restraint such as lack of space or tethering. In such cases, if monotony was perceived as aversive, non-goal-related behaviours would be predicted (Chapter 3, section 4.3.3), and perseverance behaviours may be expected in some situations (e.g. where the task is perceived as meaningful and resources that support cognitive function such as food and water are available).

Each of the components of a task can theoretically become monotonous independently of the others when the task is repeated. This is most clearly demonstrated using examples of operant paradigms – behavioural experiments that involve training animals to perform specific tasks in a controlled setting. A commonly trained task is the lever-press, in which the animal is trained to press a lever down for access to a food reward (Wilkenfield et al., 1992). In this task, the cue is the stimulus that signals that the contingent outcome (i.e. food reward) is available (e.g. the presentation of the lever), the behaviour is pressing the lever down, and the outcome is access to the food reward. The animal can be trained to associate multiple different cues, such as the illumination of a light and an auditory tone, with a single behaviour and outcome. It can also be taught that different behaviours (e.g. beaching, back flips, and tailslaps in a porpoise; Pryor et al., 1969) in response to the same cue result in the same outcome. In addition, the animal can be trained to respond to a cue with a specific behaviour for a varying outcome such as different types of food (Mcsweeney & Roll, 1998). This suggests that there is potential for animals to experience task-related boredom due to monotony in different components of a single task, demonstrating a need to investigate how animals respond to monotony in each component.

A task that does not change in any component across repetitions is expected to be perceived as monotonous and potentially lead to boredom, while on the other hand a task that changes in all three components across repetitions is unlearnable due to inconsistent contingencies. It is therefore generally assumed that some degree of change in at least one component of a task is important to facilitate ongoing task engagement (Krebs & Watters, 2017), but how the degree of change in each component contributes to boredom is unclear.

Most research to date investigating operant contingencies has focused on aspects of behaviours that are directly related to task performance such as response latency (e.g. Mar et al., 2013). These behaviours may reflect changes in cognitive processes such as attention and working memory, but on their own do not clearly indicate the likelihood of boredom. To recognise whether boredom occurs during a task, it would be useful to observe patterns of behaviour directed towards the self or wider environment, interpreted in the context of resource/demand matching, task meaning and judgement of control/restriction.

According to the model of behavioural responses to boredom presented in the previous chapter, task monotony would be predicted to lead to an excess of available cognitive resources relative to demand in the short-term, but over time this would be expected to decline due to the need for attention to be sustained endogenously (Chapter 1, section 2.5.1), eventually leading to a lack of cognitive resources relative to demand. When there is a resource-demand mismatch, if the task is perceived as meaningful and the animal judges their control to be adequate, then goal-perseverance patterns such as eating or drinking followed by a return to the task would be expected. If the task is not perceived as meaningful and the animal judges their control to be adequate, then goal-switching behaviours such as exploration and engagement in alternative tasks would be expected.

Where the animal judges their control to be low (e.g. where required resources such as food, water, or alternative tasks are unavailable), non-goal-related behaviours such as awake inactivity would be expected. Understanding the wider behavioural patterns that occur during task monotony would contribute to bridging the gap between the task-focussed concept of boredom in humans and the environment-focussed concept of boredom in animals.

2.1.2. Resource monotony

It is common for animals to be provided with resources the sensory qualities of which don't change across repeated presentations. Examples of this include feeding animals the same thing every day or repeatedly giving them the same objects to interact with. This could be interpreted as monotony in the cue component of the relevant task, but it is discussed here in the context of resource categories because monotony in some categories may be aversive while in others it is unlikely to be so, depending on the species and its evolutionary life-history. To demonstrate, an animal might prefer regular change in the specific foods that they consume but prefer a greater degree of monotony in the specific shelter that they rest in or social companions with which they interact. Consistent with this approach, resources are regularly categorized in the development of enrichment strategies, usually according to their physical properties (e.g. structural, Norman et al., 2019; substrate, Haskell et al., 1996) or the kinds of behaviour that they facilitate (e.g. foraging, Goodwin et al., 2002).

As part of enrichment strategies, interactive objects are often provided to captive wild and domestic animals to facilitate highly motivated behaviours. Such objects are most often designed to provide a contingent outcome (usually food) when they are manipulated (e.g. Anderson et al., 2010; Clark et al., 2023; Clegg et al., 2023), meaning that interacting with such objects can be thought of as a task and considered in terms of the three task components discussed above. However, objects can also be considered at the resource level, which, rather than prompting the question of how to generate change in different components of the task, prompts the question of whether change is preferred at all. Considering monotony at the level of the resource category highlights the need to examine in which categories change is important and in which stability is needed for different species.

Broadly, it is expected that generalism would be associated with aversion to monotony, while specialism would be associated with preference for monotony. As mentioned in Chapter 1 (section 1.3), generalism should be considered relative to a specific resource category. As described above, koalas would not be expected to be averse to dietary monotony because they are dietary specialists. However, koalas also maintain large home ranges (up to 300 hectares) that they move through regularly to access different trees when foraging (Davies et al., 2013). Thus, these animals might be averse to monotony in some features of their spatial surroundings, motivating them to change locations regularly. To understand how monotony impacts the welfare of specific animals, it is therefore necessary to examine the ways that resource monotony might impact their evolutionary fitness within their species' niche.

The most studied example of resource monotony in an animal context is a lack of variety in the diet (Manteca et al., 2008). A range of species demonstrate a preference for change in their food. For example, lambs prefer to consume a variety of different flavours over a single preferred flavour (Scott & Provenza, 1998). Similarly, Capuchin monkeys (*Cebus apella*) will select access to a choice among 10 different food items over access to a single preferred food item (Addessi et al., 2010). Consistent with the value of change, repeated exposure to a particular food (i.e. nutritional monotony) over days to weeks is associated with a decrease in the acceptance and consumption of that food in some species (Hetherington et al., 2002).

Studies of dietary monotony are limited to a select range of mammalian species that are of importance to production and biomedical industries, and these species tend to be adapted to consume varied diets (i.e. are dietary generalists). For example, the diet of wild Capuchin monkeys includes fruit, seeds, flowers, leaves, and roots (Galetti & Pedroni, 1994), and they will also consume novel foods when available, including crackers and cheese (Visalberghi et al., 2003). The general pattern of preference for dietary variety would not be expected to follow for species that have specialist diets.

In contrast, monotony in the provision of resources that are used for safety, such as structural features used for escape or shelter, is less likely to be aversive for many animals.

Those that are adapted to live in small, defined home ranges may prefer that their access to such resources is stable and predictable. Being familiar with available escape routes reduces escape latencies (Brown, 2001), suggesting that generating change in the provision of these resources may compromise welfare by inducing fear or anxiety related to compromising the ability to escape. However, this may not be the case for animals that are adapted for travelling long distances and continually re-assessing the availability of escape routes and shelter as they relocate (e.g. migratory animals). This demonstrates the value of considering monotony and change at the level of resource categories when designing or assessing animal environments, as it prompts the consideration of not only what resources animals of different species require but also how stable (i.e. monotonous) they require them to be.

The welfare impact of resource monotony is expected to be highly dependent on species-level adaptations and traits, and here I have suggested a broad type of adaptation (i.e. generalism or specialism) that seems likely to influence whether an animal has an aversion to or preference for monotony in various resources. Future research should assess how reliably generalism versus specialism predicts aversion to monotony and seek to explore other traits that influence how animals respond to change in key resources.

2.1.3. Social monotony

The social environment of animals can also lack change, and the welfare impact of this is likely to be closely linked with aspects of evolutionary life-strategy relating to sociality and breeding; some species would be expected to prefer social monotony while other species find it aversive. This may also vary within a group across seasons (e.g. during breeding seasons) and life-stages (e.g. natal dispersal of juvenile males). Social monotony is distinct from other types of monotony because it considers the role of other agents in the environment, each with their own capacity to generate change.

Social monotony can occur in a group of any size if group membership does not change over time. It may occur in small groups, where an individual animal has only a few options for social interaction, in larger groups where social structures influence access to certain individuals (Pacheco & Madden, 2021), or where individuals are actively prevented from accessing other specific individuals (e.g. mate guarding; Alberts et al., 1996). When there is a low degree of change in a social group, members of the group are able to learn the habits, tendencies, and predispositions of other members. Over time, this may lead to predictable and monotonous interactions between individuals, and monotony in the changes that certain members of the group produce. This situation is common in domestic settings, particularly for indoor-only or group-caged or tanked pets.

Animals that are adapted for living in stable social environments may not find social monotony aversive and may even find a high degree of social change stressful or fear-inducing. On the other hand, animals that are adapted for changeable social environments may be averse to social monotony. Most studies examining group stability compare the interactions of animals with familiar and unfamiliar conspecifics (e.g. Barber & Wright, 2001; Gutmann et al., 2015; Luo et al., 2022), but not with familiar conspecifics that the animal has not interacted with recently. Future research could examine how providing access to different familiar animals influences behaviour.

To summarize, three different "types" of monotony have been discussed here. Considering monotony at the level of discrete tasks prompts us to explore how generating change in different components of a task influences not only how animals perform on the task, but also their emotions and feelings towards repeated interactions with the task – including whether they experience boredom. Considering monotony at the level of resource categories like food or shelter prompts us to explore which resources should be varied and which resources should be kept monotonous for animals of different species. Finally, considering monotony at the level of social interactions highlights a need for further research examining the effect of social change in different species.

2.2. Patterns of change

As well as the type of change, the pattern of change over time may influence how animals respond to their environment and to specific resources within it. Whereas the previous sections have focused on changes in the qualities of specific resources or events across repeated presentations, this section focusses on the timing of such presentations. Monotony may refer to a complete lack of change over time, to frequent but highly regular change, or to infrequent change. All of these conditions facilitate habituation (see section 3.2) and therefore reflect low demand on cognitive resources. In humans, such patterns have been used in task-based paradigms to study boredom and its related correlates. Complete lack of change over time is used in waiting paradigms (e.g. Witowska et al., 2020), infrequent change is used in monitoring paradigms (e.g. Thackray et al., 1977), and frequent but highly regular change is used in boredom choice paradigms (e.g. Seiler et al., 2022). Although such task-based paradigms expose subjects to monotony on relatively short timescales (i.e. minutes to hours), these patterns can also occur over larger timescales such as days to weeks or longer.

Most of the focus in animal enrichment research is on examining how providing specific resources influences animals, but the pattern in which those resources are presented – and the periods of low change during and between presentations – is generally not accounted for in the study design (but see section 3.2 below for a discussion of current research on habituation in animals). The responses of animals to change are highly dependent on perception-related factors such as predictability and familiarity, so it is impossible to discuss such responses independently. Therefore, current knowledge of how animals respond to various patterns of change is discussed further in section 3.1. Here, I will simply describe how the three patterns of monotony introduced here may occur in animal environments.

Some animals may be housed in situations that involve a complete lack of change over time in the availability of resources and social companions. Both barren and complex environments may be monotonous in this way. For example, an ornamental fish-tank may house fish of multiple species that are provided with plants, gravel, hiding places, and a bubbler. This tank would be considered by many to be complex, but if none of these objects are moved, replaced, or otherwise changed, the environment could be considered monotonous in terms of resources and social interactions.

Other environments may change but only in very regular and predictable ways. Very few environments are truly static due to the occurrence of diurnal rhythms such as changes in light and temperature, or artificial simulations of these rhythms in totally controlled animal management environments (e.g. laboratories and nocturnal houses). However, these rhythms reflect regular predictable changes which could be perceived to be monotonous because these changes quickly become familiar. Other changes that fit this pattern include the daily provision of food, or regular opportunities to change locations (e.g. daily walks for dogs or accessibility of off-exhibit areas overnight for animals in zoos).

Other forms of change may occur infrequently or irregularly. For example, in highly controlled environments such as laboratories, auditory and visual changes may occur when personnel enter or leave. Similarly, in outdoor housing systems animals may be confined to the same space for weeks or months with irregular interactions with stock handlers for health checks.

The effect of these patterns of change on animals depends on how they are perceived. Thus, individual factors such as prior experience are expected to influence how animals respond to monotony. Individual factors are outside the current scope, but predictability, familiarity, and judgement of control represent aspects of the interaction between the objective presentation of monotony and individual factors and are described here as "perception-related" factors.

3. Perception-related factors influencing how animals respond to monotony

The above sections described the objective presentation of monotony as a lack of change in the components of discrete tasks, in the provision of various resources, and in access to social companions, which may occur in totality, in regular patterns, or infrequently and without discernable patterns. While these objective factors all influence how monotony impacts animals, ultimately this influence is moderated by the perceptions of the animals themselves.

The perception of monotony results from the subject's interpretation of their environment or situation (Perkins & Hill, 1985; Snell-Rood & Steck, 2019). In other words, although monotony can be objectively defined and generated according to its type and pattern of presentation, an environment that appears to one observer to be highly monotonous might seem less monotonous to another. This section discusses the roles of factors that are likely to underlie the perception of monotony as a result of interaction between subject-related and objective factors.

Predictability and familiarity describe processes that influence the availability of cognitive resources by filtering incoming information. An event that is highly predictable does not necessitate sustained monitoring prior to its occurrence (i.e. executive attention, which depletes over time), while an event that is familiar does not necessitate information-gathering (i.e. attention and working memory). Thus, highly predictable and familiar changes would be expected to induce a relatively low demand on cognitive resources. If boredom is caused by over-availability of resources relative to demand, unpredictable and unfamiliar changes would therefore be expected to be more effective at alleviating it, whereas when it is caused by under-availability of resources relative to demand (e.g. when an animal is sleep-deprived) predictable and familiar changes might be preferred.

3.1. Predictability

As noted above, monotony may occur as a result of repeated, predictable changes (Burn, 2017). Over time, patterns may emerge in any regular and consistent feature of change. For example, an interactive object might be added to an environment at regular intervals. These patterns make up specific routines that can be learned and predicted by the subject (Bassett & Buchanan-Smith, 2007; Gottlieb et al., 2013).

Two types of predictability have previously been identified: signaled and temporal (Bassett & Buchanan-Smith, 2007). Signaled predictability refers to the use of signals preceding the onset of an event such as an electric shock or the provision of food. This is less relevant to the discussion of monotony because the signal is itself a change that may occur at unpredictable times. Temporal predictability, on the other hand, describes the regularity of change. Changes that occur at fixed intervals are more predictable than those with variable intervals. Situations in which salient events are temporally predictable may be perceived as more monotonous because there is a lower requirement for sustained monitoring between events. In other words, because the animal can predict the timing of the event, they do not need to deploy as many attentional resources to prepare for the event prior to its onset, leaving those resources available for other uses.

While a high degree of predictability is likely to lead to the perception of monotony, its impact is likely to depend on the wider situation. For example, predictability has been shown to mediate stress across a range of species (Bassett & Buchanan-Smith, 2007). However, this effect is not always consistent across studies and seems to depend to some extent on the nature of the event being predicted (i.e. whether the event is appetitive or aversive) and the measures of stress used (e.g. physiological or behavioural measures) (Bassett & Buchanan-Smith, 2007), Generally, for appetitive events, predictability is associated with fewer stress-related behaviours (Gottlieb et al., 2013; Zupan et al., 2020). These findings suggest that in certain circumstances monotony due to high temporal predictability might promote enhanced welfare rather than creating compromise.

3.2. Familiarity and habituation

To perceive a lack of change in an environment or situation, the subject must have some level of familiarity with that environment or situation, gained through time spent exposed to the monotonous feature. Familiarity can be considered in relation to the environment itself and to specific events that introduce change to that environment, such as the introduction of objects.

To illustrate the idea of familiarity with the environment, consider the use of open field tests for assessing how animals respond to novelty. In an open field test, subjects are introduced to a barren environment and their behaviour is monitored over time (Avni et al., 2006; Finger et al., 2016; Montiglio et al., 2010; Wormald et al., 2016). In this test, the environment is novel to the subjects, meaning that they have no previous experience in that environment and the demand on their cognitive resources is high as they must deploy attention and working memory resources to gather information about all of the stimuli present. Although the environment does not change over the course of the test (and is therefore *objectively* monotonous for the full 2-15 minute duration; Gould et al., 2009), it is unlikely to be perceived as monotonous to the *subjects*, who are not familiar enough with the environment to judge whether change occurs in a predictable pattern – as evidenced by the ongoing anxiety-like responses observed in such tests (Prut & Belzung, 2003).

The duration of exposure is particularly important to the development of familiarity. In the above example, the open field test is unlikely to be perceived as monotonous immediately after the animal is introduced to the new environment, but if the animal was left there for long enough to gather adequate information about all of the available stimuli, then it may eventually perceive monotony. The duration required to achieve this depends on how long it takes to gather sufficient information about the predictability (i.e. frequency and pattern) of changes to reduce the demand on cognitive resources. This is influenced by the complexity of the environment, and any patterns of change within it.

If increasing familiarity with a stimulus leads to a perception of monotony and monotony in that stimulus is aversive, then the animal would be expected to interact less with it. Having said that, if the stimulus provides a meaningful interaction, then goal-perseverance patterns would be expected, whereby the animal repeatedly engages and disengages with the stimulus. A decline in interactions with specific stimuli (e.g. enrichment objects) over time is often framed as habituation (e.g. Anderson et al., 2010; Tarou & Bashaw, 2007). Habituation describes a non-associative learning process in which response to a stimulus declines after repeated presentations (Rankin et al., 2009). This process filters out irrelevant sensory inputs and allows the animal to focus on salient stimuli.

The term habituation may be used differently across disciplines. In psychology, habituation refers to sensory attenuation over time, such as no longer hearing a clock ticking, usually recognized by the attenuation of a behavioural or neural response during the repeated presentation of a stimulus (Jamal et al., 2021; Thompson, 2009). It may also be used to describe a learning process in which the subject learns that a stimulus is not associated with a contingent outcome, which also leads to a behavioural response attenuation (Rankin et al., 2009). In environmental enrichment, habituation is used in relation to a decline in interactions with an enrichment device (e.g. Anderson et al., 2010; Kuczaj et al., 2002; Tarou & Bashaw, 2007). These uses all describe a process of "getting used to" a stimulus but seem to describe the process at different levels by focusing on different outcomes.

In the context of boredom, habituation reflects a change in cognitive processing that reduces demand on resources such as attention and working memory, thereby increasing their availability. Where this process results in the availability of excess cognitive resources relative to demand, boredom would be expected to occur. However, as with studies of environmental complexity, most investigations of habituation in animals collapse behavioural data and assess the total duration of interaction with a stimulus rather than characterising broader behavioural patterns that are required to recognise boredom (e.g. Anderson et al., 2010; Bigiani & Pilenga, 2024; Russell et al., 2024). Some studies assess behaviours that are not directed at the stimulus such as self-grooming, abnormal repetitive behaviours, and social interactions (e.g. Damasceno et al., 2017), but likewise these behaviours are reported as durations so behaviour patterns indicative of goal-switching and goal-perseverance cannot be assessed.

A decline in response due to habituation can develop very quickly. For example, the proportion of time pigs spent interacting with a novel object declined by over 80% over five days (Guy et al., 2013), while Apple & Craig (1992) observed a significant decline in interactions over a single hour. Similarly, cats habituate to an unchanging toy within three sessions of play lasting for only two minutes (Hall et al., 2002). However, other factors may increase the time taken to reach familiarity, including environmental complexity and intermittent exposure.

In a complex environment, the subject must investigate more stimuli and track changes in those stimuli over time to develop familiarity. Thus, it may be that animals can go for longer in complex environments before developing a perception of monotony. Supporting this idea, adult mice exhibited exploratory behaviour towards novel objects for a longer duration when the objects were all different (i.e. more complex) compared to when the objects were all the same (Brennan et al., 1984). Correspondingly, when an animal is exposed to an environment or stimulus intermittently they have less opportunity to investigate and track changes over time, and must remember the patterns they observe, slowing down the development of familiarity.

Familiar change (i.e. intermittently re-introducing a familiar stimulus) may alleviate perceived monotony even when it is predictable, but to a lesser extent than novelty. For example, when a food puzzle was presented to captive sloth bears (*Melursus ursinus*) on intermittent days, they spent more time interacting with it per day compared to when it was provided over five consecutive days (Anderson et al., 2010). This could be explained by a drive to gather information and "check" it against the information remembered from the last interaction with that stimulus (Brooks et al., 2023) – providing an opportunity to deploy cognitive resources. However, compared to the provision of novel change, the influence of familiar change on animals is understudied. Studies that assess the behavioural responses of animals to a familiar object tend to only compare it against a novel object (e.g. Ameen-Ali et al., 2021; Gifford et al., 2007). For example, piglets given a choice to interact with a familiar or novel object spent more time interacting with the novel option (Wood-Gush & Vestergaard, 1991), but how they would spend time with the familiar object if it was the only change provided is unclear. This is an important knowledge gap, particularly for the development of enrichment strategies for animals that are averse to novelty, as providing familiar change could reduce monotony without stimulating fear for such animals.

Overall, increased familiarity is expected to contribute to the perception of monotony over time through habituation, but higher environmental complexity and intermittent exposure may slow down this process. Animals with a high availability of cognitive resources relative to demand (such as those in highly monotonous environments) would be expected to prefer novelty as it provides an opportunity to deploy excess resources. On the other hand, animals with a low availability of resources would be expected to prefer familiarity as fewer resources are required for information-gathering.

3.3. Judgement of control/restriction

In previous chapters, restriction has been presented as an antecedent of boredom and a factor influencing how boredom might be expressed behaviourally. Here, restriction is related to the *perception* of monotony as an environmental antecedent to boredom.

Judgement of control is integral to the perception of monotony because, assuming that monotony is aversive to the subject, some element of restriction must be present to prevent them from taking action to generate change and thereby alleviate the perceived monotony (Snell-Rood & Steck, 2019). When a situation has a greater degree of restriction, the intensity of monotony perceived may also be greater because the subject is less able to create change through their own actions to alleviate it. In humans, there is no direct evidence investigating how restriction influences the perception of and response to monotony, but task monotony is usually studied under highly restrictive conditions such as in controlled laboratory settings (e.g. Seiler et al., 2022).

Despite this close interaction, restriction and perception of monotony can be manipulated independently in some cases. In a highly restrictive environment, changes may be introduced that do not provide the animal with greater control. An example of this is leaving a radio turned on; the animal is exposed to changes in auditory stimulation which reduces the degree of *objective* monotony and may provide an opportunity to use attentional resources, but this does not facilitate any goal-directed behaviours additional to those already available. In addition, depending on what is played, *perceived* monotony may increase over time as the animal learns to predict patterns in the auditory stimuli and becomes familiar with the various sounds. Similarly, in an *objectively* monotonous environment animals can be provided with resources that allow a greater degree of control, but those resources and the goal-directed tasks associated with them can still be *perceived* as monotonous over time as the animal becomes familiar with those resources if additional changes are not introduced. This further demonstrates how more complex environments may also become perceived as monotonous if they are unchanging.

4. Conclusion

The purpose of this chapter was to examine the concept of monotony as a potential antecedent to boredom and the features that influence its perception by, and emotional significance to, different animals. Three broad types of monotony were introduced: task, resource, and social monotony. Task monotony may be perceived in three different components of a task, and it is currently unclear how monotony in each component contributes to the behavioural responses of animals – particularly those indicative of boredom. Perception of monotony and its emotional significance can also be considered in the context of resource categories that are ecologically relevant for a particular animal, and animals may be more averse to monotony in some resources than others. This is proposed to relate to the niche that animals are adapted for and highlights the need to consider the specific evolutionary background of a species when considering which resources to change versus which to keep stable. Monotony may also occur in an animals' social environment, but as many social species show a preference for familiar conspecifics future work might investigate how animals respond to familiar social change.

Within each type of monotony, the pattern of presentation may influence the duration required for the animal to develop accurate predictions of and familiarity with changes that occur. Changes that are more predictable and familiar are expected to place a lower demand on cognitive resources; for animals in restrictive, low complexity environments this may increase the probability that they perceive monotony as aversive and experience boredom.

This chapter demonstrated a range of factors that may influence whether monotony functions as an antecedent to boredom in animals of different species and in different situations – one of which being task monotony. This further highlights a need to examine the effect of monotony in different task components, using continuous monitoring to identify behavioural patterns indicative of boredom. The next chapter presents the development of an experimental paradigm aiming to provide a starting place for this investigation by exploring how rats respond to task monotony.

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Chapter 5, Development of a method to investigate how rats respond to task monotony

1. Introduction

Current evidence suggests that animals of at least some species find at least some forms of monotony aversive. However, there remains a large gap in our understanding of how monotonous situations affect animals. Of the types of monotony presented in Chapter 4, task monotony seems to most closely relate to manipulations of boredom used in human research (Chapter 3, section 2.5.1), indicating that exploring how animals respond to repetitive tasks could contribute to bridging the gap between current environment-focussed understandings of boredom in animals and task-focussed understandings in humans. This form of monotony reflects a manipulation of environmental demand on cognitive resources, lowering demand by reducing the requirement to deploy resources in attending to any changes over time. This chapter describes the development of a task monotony paradigm that can be used to assess the occurrence of boredom-related behavioural patterns predicted by the model presented in Chapter 3.

As well as furthering our understanding of the role of monotony in boredom, this chapter focusses on task monotony for practical reasons. A task monotony paradigm can be designed to be performed in a short timeframe (a few hours per week rather than continuously over months), making it more feasible to use continuous behavioural monitoring to capture the patterns that occur over time during exposure to monotony. This facilitates the recognition of temporal patterns of behaviour, such as those predicted by the model presented in Chapter 3.

The key objective of this chapter is to outline the development of a method for evaluating behavioural responses of animals to task monotony. The paradigm presented in this chapter has been designed as a pilot study to determine key methodological details that cannot be drawn from existing literature (section 2.3). Due to challenges outside my control (section 5), the planned collection of data for this pilot study could only be completed with a single animal during the term of this PhD, and the behavioural data collected was not analyzed in time for inclusion. Thus, a secondary objective of this chapter is to reflect on the challenges faced during the development of this paradigm. A discussion of further development and potential applications of this paradigm can be found in Chapter 6.

2. Protocol design

2.1. Selection of animal model

Before designing a method for creating task-monotony, it was necessary to first determine an appropriate animal species to use. As discussed in Chapter 1, current theory suggests that boredom is most likely to occur in generalist species (Burn, 2017), and the logic behind this conclusion is also applicable to aversion to monotony (Chapter 4). Therefore, a generalist species was selected for the pilot study.

After establishing that the study would use a generalist mammal, the next consideration was accessibility and ease of keeping. Small mammals are commonly bred for scientific purposes; they are therefore accessible from breeding facilities and can be kept at relatively low cost in a laboratory. Mammals that can be sourced and kept in NZ include mice, guinea pigs, and rats. Mustelids (e.g. mink) other than ferrets are prohibited under NZ law (Hazardous Substances and New Organisms Act 1992), while ferrets are classified as unwanted organisms (Biosecurity Act 1993) and cannot be bred or sold.

Using a task to generate monotony requires animals to be trained to perform tasks, with preference for animals that can learn to do so quickly. Rodents were a clear choice due to a well-established tradition of use in operant paradigms within memory and cognition research. Finally, rats were selected rather than mice for ease of handling and because their larger size makes it more likely that they could trigger a response from a touchscreen used to present the task (section 2.2).

The final decision relating to the selection of animals was the choice of strain from a range of common laboratory strains including Long Evans, Wistar, and Sprague Dawley. Initially, a hooded strain (with pigmented eyes) was selected due to concerns about the visual acuity of albino strains which was expected to influence their ability to learn a screen-based task. However, at the time of development the sourcing of animals within NZ was disrupted by COVID-19 and adult animals could not be imported for the purposes of piloting. The strain most readily available in NZ was Sprague Dawley. Counter to my original assumption, Sprague Dawley rats have previously been used in touchscreen paradigms and readily learn to discriminate visual stimuli (Bussey et al., 2008). Thus, Sprague Dawley rats were used for piloting.

2.2. Principles of training rats to perform a task

To characterize rats' responses to task monotony, it is first necessary to train them to perform the desired task. This requires several stages of training, applying well-understood cognitive processes of operant and classical conditioning which are described briefly below.

Using a repetitive task to generate monotony first requires the animals to be trained to perform the task reliably when cued. This can be achieved through operant conditioning. Operant conditioning describes training that manipulates "trial-and-error" learning processes to teach an animal the relationship between performing a specific behaviour and an immediate consequence (Akpan & Kennedy, 2020). Every time the animal performs the 'target behaviour', the behaviour can either be reinforced to encourage them to repeat it or punished to encourage them not to repeat it. Reinforcement, to increase the likelihood of the behaviour being repeated, may consist of providing a rewarding stimulus such as food (positive reinforcement) or removing an aversive stimulus such as a loud noise or electric shock (negative reinforcement). Punishment may consist of providing an aversive stimulus (positive punishment) or removing a rewarding stimulus (negative punishment). For the purposes of this research, positive reinforcement was most suitable because it can be used to train a task without requiring the use of aversive stimuli or the removal of rewarding stimuli which can also cause negative experiences for the subject.

In this kind of behavioural testing paradigm, it is often necessary for animals to perform behaviours that are not part of their species-specific repertoire. In a training sense, that means the animals are not likely to perform the correct behaviour by chance and it is not feasible to simply wait for the animal to perform the target behaviour and then reinforce it. Instead, a method called successive approximation may be used (Blackman, 2017). The researcher can reinforce behaviours that approximate the target behaviour and over time refine the criteria for reinforcement until the target behaviour is reached (Blackman, 2017; Horner et al., 2013). For example, if the target behaviour is pressing a lever the researcher might set the initial reinforcement criteria as "touch the lever with any body part" to receive a reward. When the animal can repeatedly meet this criterion, the researcher can then refine it to "touch the lever with either front foot" before the reward is given (i.e. touching the lever with a different body part is no longer rewarded). When the animal can repeatedly meet the new criterion, the researcher can repeat the process to further refine it and move towards the final target behaviour.

When training animals using positive reinforcement, the animal must learn not only the relationship between the behaviour and its consequence, but also when reinforcement is available and how to access it. This is achieved through classical (or Pavlovian) conditioning (Akpan & Kennedy, 2020). Classical conditioning describes training an animal to recognise the relationship between a biologically salient stimulus such as food (unconditioned stimulus, UCS) and a neutral or non-salient stimulus (conditioned stimulus, CS). When training in an experimental context, animals can be trained to associate a tone or a light turning on with the presentation of their reinforcement. Through this association, the animal can recognise that reinforcement is available when they hear the tone or see the light turn on. This is achieved through repeated "forward-pairing": presenting the CS (e.g. the light) immediately before presenting the UCS (reinforcer) (Wolf et al., 2014). When operant conditioning is subsequently applied, the CS functions as a "marker" signal, telling the animal that they have successfully completed the task and reinforcement is available (Blackman, 2017). Having a marker signal makes operant conditioning more efficient, as the researcher can precisely "mark" the moment that the animal performs the correct behaviour. It is through the process of classical conditioning that the animal also learns where to access their reinforcement if required.

Operant and classical conditioning can be applied to teach an animal to perform a task in a controlled experimental setting by using an operant chamber. This is a box of appropriate size for the study species that is equipped with operandi, devices upon which the animal can exert a response such as a lever or hanging chain, and an LED light or speaker (for presenting the marker signal). The chamber also contains a means of delivering the reinforcer, usually a food dispenser. These components are connected to software that can automatically detect manipulation of the operandi and dispense reinforcement.

Over the past two decades, researchers have developed the use of touchscreen-enabled operant chambers for their research on rodent cognition (e.g. Heath et al., 2016; Horner et al., 2013; Kim et al., 2017; Mar et al., 2013). This approach replaces mechanical devices (levers, chains) with a touchscreen that can be used to present a wide range of stimuli. A benefit is that infra-red photocells in the screen are used to detect touch, meaning that the animals do not need to exert physical pressure for the screen to register a touch response (Horner et al., 2013). This means that in studies requiring multiple responses physical fatigue is less likely to occur. However, commercially available chambers are very expensive, making them unfeasible for many researchers. A relatively inexpensive iPad can be programmed to detect the touch of a rat paw or nose, and can be integrated into a custom-built operant chamber comparatively cheaply (Wolf et al., 2014).

The process of training animals to use touchscreen-enabled operant chambers is similar to that required for traditional chambers utilising physical operandi, whereby a shaping process involving classical conditioning and operant successive approximation is used to train the required task. Touchscreen-enabled chambers function by displaying a stimulus on the touchscreen that the animal is trained to touch to access reinforcement. The stimulus can be altered in various ways by changing the shape, size, colour, and location on the screen, and multiple shapes can be presented concurrently. This functionality allows for more complex testing options. Rats of various strains are capable of learning to perform touchscreen-based tasks (Horner et al., 2013; Wolf et al., 2014).

2.3. Paradigm criteria for evaluating responses to task monotony

To evaluate rats' responses to task monotony, an operant testing paradigm should meet three criteria. First, in the monotony treatment there should be minimal or no variation between repetitions in the cue used to signal the task, the behaviour required to successfully complete the task, or the contingent outcome (i.e. the reward). A change in any of these features may increase demand on cognitive resources and thus be perceived by the animal as a break in the monotony. Secondly, testing sessions (periods during which the task and reinforcer are presented multiple times) should be of appropriate duration for the animal to become familiar with the environment and task, lowering the demand they place on cognitive resources and increasing the likelihood of the task being perceived as monotonous (see Chapter 4, section 3.2). Finally, the task should require limited physical exertion, as physical fatigue may reduce the availability of cognitive resources, lessening the resource-demand mismatch and thereby reducing the likelihood of boredom occurring. While many different operant testing paradigms are available, none have been designed that meet all of these criteria.

Some existing paradigms present the same task repeatedly but introduce variation (i.e. increased demand on cognitive resources) to test how the animal responds. For example, the '5-choice serial reaction time task' is designed to assess attention and impulsivity in rats (Chapter 3, section 3.1.2; Schneider et al., 2011). In this task, the animal must repeatedly respond to the illumination of a nose-poke hole, but any one of five holes may be illuminated in any order, introducing constant variability into the task (Hoffman, 2015). Likewise, in the 'paired associate learning task', used to assess spatial memory in rat models of Alzheimer's and schizophrenia (Talpos et al., 2009), the animal is trained to associate three different images with three respective spatial locations. It is then presented with two of the images, one in the correct location and one in an incorrect location, and must select the image that is in the correct location to achieve the reward (Kim et al., 2016; Talpos et al., 2009). As the image in the correct location changes between trials, this task also has inherent variability.

Although it would be possible to train rats to perform such tasks and then present them monotonously, this requires first training the animals to expect variation (Hervig et al., 2023; Smith et al., 2022). As discussed in Chapter 4, monotony is determined by the subject's perception. Therefore, at this stage of developing a task monotony paradigm, it is preferable to avoid setting an expectation of variation even during training, as far as is practicable. Thus, as originally presented, such paradigms do not meet the first criteria for a task evaluating responses to monotony: no variation in the task cue.

Other paradigms use genuinely repetitive tasks but implement short, intermittent sessions. For example, repeated reaching tasks have been used with rodents to model repetitive motion injuries such as carpal tunnel syndrome (Al-Shatti et al., 2005; Barbe et al., 2013; Coq et al., 2009). In such tasks, rats are required to reach into a tube to grasp food pellets repeatedly. However, although the rats are tested for up to two hours per test day, this is broken into 30-minute sessions. Splitting sessions in this way may allow the animals to learn to anticipate the beginning and end of the monotonous condition, which is likely to alter their perception and behavioural responses (Anderson et al., 2020; Hayes et al., 2021; Sevilla et al., 2016). In particular, if animals anticipate the end of the session and consequent removal of the reinforcer (e.g. a highly valued food reward) after a limited time, they may exhibit behaviours reflecting increased motivation to access the reinforcer while it is available (Bake et al., 2014). In addition, using intermittent sessions may also interfere with the development of familiarity with the environment and test. Therefore, the responses of animals exposed to repeated short-term task monotony may be confounded by anticipatory behaviour or low familiarity and therefore not meet the second criteria of appropriate duration to be perceived as monotonous. However, it is not clear how long individual sessions should be to facilitate familiarity and also prevent animals from anticipating the end of reinforcer availability (see below).

Tasks that require physical exertion during testing may lead to injury or fatigue. In the above example of the repeated reaching task, the explicit purpose of the task is to induce limb pathologies comparable to repetitive motion injuries, meaning it is not suitable for assessing responses to monotony (Al-Shatti et al., 2005; Barbe et al., 2013; Coq et al., 2009). Similarly, repeated wheel- or treadmill-running is not a useful task for a monotony paradigm due to the potential for fatigue (Stutz et al., 2019), which may influence behavioural responses over time by reducing the availability of cognitive resources. To assess the response of animals to monotony *per se*, it is important to avoid confounding a monotony-response with a pain or fatigue response.

There is limited existing information to guide the temporal structure of the protocol when selecting the duration of testing sessions and how many sessions to use under monotonous vs variable conditions. Previous research suggests that the duration of sessions influences the behaviour of rodents during operant conditioning paradigms. For example, mice exposed to a task (lever press or nose poke) for 10 sessions of 90 minutes' duration over a period of 11 days showed a decline in response rate in the last 30 minutes, although a decline was not seen in mice tested in 30 or 60 minute sessions (Haluk & Wickman, 2010). The decline in response rate by mice in longer sessions was attributed to satiation due to food rewarding (section 5.5) but may also have been related to increasing familiarity, suggesting that a duration greater than 60 minutes is required to facilitate adequate familiarity with the testing environment.

The effect of repeated sessions on rodent behaviour is less clear. In the above study, mice did not show a significant decline in the average number of responses per session over the

10 sessions (Haluk & Wickman, 2010). This is one of very few studies that repeat operant tests without making changes to the reinforcement schedule between sessions (e.g. Jojola et al., 2007), leading to changes in behaviour that are associated with a different rate of reinforcement rather than the repetition of testing. Thus, in developing the current paradigm to evaluate task monotony, both the number of sessions and the duration of each session needed for animals to perceive the task as monotonous must be considered.

The protocol presented in this chapter is designed as a pilot study, to be used with a small number of animals in order to determine important methodological details that cannot be drawn from the existing literature, namely, the session duration and number of sessions required to observe a change in behaviour in response to task monotony. In addition, the task being used to generate monotony - while based on a similar previously used task (Wolf et al., 2014) - is being applied in a novel way so it is necessary to assess the feasibility of training rats to perform the task.

The specific objectives of the pilot study are to:

- Assess the feasibility of task acquisition by Sprague Dawley rats using a touchscreen-enabled operant chamber
- Identify the optimal duration of each session and overall number of sessions required to observe changes in behaviour patterns associated with the occurrence of boredom
- Identify whether gross differences in behaviour and performance patterns are apparent between animals exposed to a monotonous task and animals presented with a varying task when all other features of the paradigm are controlled (i.e. confirm that the two conditions induce sufficiently different degrees of cognitive demand)

3. Materials and methods

3.1. Ethics statement

Approval for the study procedures was granted by the Massey University Animal Ethics Committee (MUAEC Protocol 21/16). All procedures were carried out with the Massey

University Code of Ethical Conduct for the Use of Animals for Research, Testing, and Teaching.

3.2. Animals and housing

Due to unforeseen challenges associated with rodent housing facilities (section 5), four groups of animals were used at different stages during the development of the paradigm.

Group 1, training started 26/07/21: Four adult Sprague Dawley female rats were sourced from AgResearch Ruakura. The rats were unhandled and experimentally naïve and had been raised in a large group of over thirty individuals. The rats were kept at the Animal Welfare Science and Bioethics Animal Behaviour Laboratory, Massey University. They were housed in large (1000 x 530 x 650 mm) cages with two rats per cage and the cages were furnished with tunnels, wooden chews, and platforms. Female rats were selected due to lower aggression, allowing for pair housing. The rats were kept in a temperature and light-controlled room at 23°C on a 12:12 h light:dark cycle. They were fed ad-lib on a commercial pet diet (Excel Rat Nuggets, Burgess Pet Care, England) with water freely available at all times, and their cages were cleaned fortnightly. In addition, the rats were handled regularly (four days per week) to prepare them for rehoming at the end of the study.

Group 2, training started 22/08/22: Four adult Sprague Dawley female rats were sourced from The New Zealand Institute for Plant and Food Research Limited. The rats were unhandled and experimentally naïve and had been raised in a small group of roughly ten individuals. The rats were kept at the NZ Institute for Plant and Food Research, Feed Evaluation Unit Small Animal Facility, Palmerston North. They were housed in large (1000 x 530 x 650 mm) cages with two rats per cage and the cages were furnished with tunnels, wooden chews, and platforms. The rats were kept in a heated and light-controlled room at 23-27°C on a 12:12 h light:dark cycle. They were fed ad-lib on an industry standard laboratory rodent diet (Diet 86 – Rodent Nuts, Sharpes Stock Feeds Ltd., NZ), with water freely available at all times, and their cages were cleaned weekly. In addition, the rats were handled regularly (four days per week) to prepare them for rehoming at the end of the study.

Group 3, training started 24/04/23: Two adult Sprague Dawley female rats were sourced after being used in a rodent handling class for veterinary science students. These rats were originally sourced from Plant and Food Research. They were well-handled but experimentally naïve. The rats were kept at the Animal Welfare Science and Bioethics Animal Behaviour Laboratory, Massey University. They were housed in large (1000 x 530 x 650 mm) cages with two rats per cage and the cages were furnished with tunnels, wooden chews, and platforms. The rats were kept in a temperature and light-controlled room at 23°C on a 12:12 h light:dark cycle, fed ad-lib on an industry standard laboratory rodent diet (Diet 86 – Rodent Nuts, Sharpes Stock Feeds Ltd., NZ) with water freely available at all times, and their cages were cleaned fortnightly. In addition, the rats were handled regularly (four days per week) to prepare them for rehoming at the end of the study.

Group 4, training started 14/11/23: Four adult Sprague Dawley female rats were sourced from Plant and Food Research. The rats were unhandled and experimentally naïve and had been raised in their litter group. The rats were kept at the Animal Welfare Science and Bioethics Animal Behaviour Laboratory, Massey University. They were housed in large (1000 x 530 x 650 mm) cages with two rats per cage and the cages were furnished with tunnels, wooden chews, and platforms. The rats were kept in a temperature and light-controlled room at 23°C on a 12:12h light:dark cycle, fed ad-lib on an industry standard laboratory rodent diet (Diet 86 – Rodent Nuts, Sharpes Stock Feeds Ltd., NZ) with water freely available at all times, and their cages were cleaned fortnightly. In addition, the rats were handled daily to prepare them for rehoming at the end of the study.

3.3. Equipment

A custom-built wooden operant conditioning chamber with dimensions 310W x 440L x 320H mm was fitted with a touchscreen device (iPad mini 2, Apple Inc., CA, USA), a custom-built syringe driver for dispensing liquid food rewards, and reward bowl with an infra-red sensor. After discovering inconsistent reward delivery due to dripping (section 5.3), the reward dispenser was replaced with a Switchable Liquid Dipper (#ENV-202M-S, Med Associates Inc., USA) fitted with a cup that dispensed 0.01cc of liquid at a time. The dipper was custom-fitted with an infra-sensor. The chamber was also fitted with a water bottle on the outside wall with a hole for the sipper tube to enter the chamber, allowing water to be available within the chamber at all times. In addition, a ventilation fan was located on the top panel of the chamber, over the location of the sipper tube. The touchscreen was mounted in the chamber at a 52° angle to encourage the rats to place their paws on it (Wolf et al., 2014). It was designed to display visual stimuli that the rats could be trained to touch, as well as to collect data on performance parameters such as touch locations and latencies (section 4). The touchscreen was wirelessly connected to the reward dispenser and a green LED light located over the reward bowl designed to function as a marker signal for correct responses.

The touchscreen, reward dispenser, and LED were controlled wirelessly using custom Rat Trainer software written in JavaScript using Electron framework software (OpenJS Foundation). The software connected to these components over WIFI via an ESP32 microcontroller programmed in the C programming language. The Rat Trainer software allows the researcher to manually control the stimulus presentation and reward process or to automatically control these processes with pre-set trial procedures (sections 3.4.1 – 3.4.4). In addition, the software communicates with the infra-red sensor over the reward bowl to identify when the rat has accessed the reward. The software also records data from the touchscreen, as well as session data such as number of trials, inter-trial intervals, and number of rewards accessed (section 4).

Two video cameras (Raspberry Pi 4 Model B with 5MP Night Vision Camera for Raspberry Pi, Raspberry Pi Foundation, UK) were integrated into the sides of the chamber, to provide recordings of rat behaviour from directly above in the centre and from the wall behind the touchscreen at a height of 280 mm from the floor of the chamber. The infra-red light modules from these cameras were modified by removing the light sensor (light dependent resistor) and replacing it with a set value resistor to ensure that the lights would be of consistent brightness.

The food reward used was 0.1 mL 50% sweetened condensed milk diluted with water. A liquid reinforcer was selected as this allowed finer control of the reward volume if required (e.g. to limit satiety, section 5.5). Sweetened condensed milk is a commonly used, highly palatable operant reward for rats (e.g. Brackney et al., 2021; Byrne, 2019; Nolan et al., 2011). The reward had to be diluted to facilitate delivery via syringe pump, as 100%

sweetened condensed milk was too viscous, and a 50% dilution has been previously shown to effectively reinforce operant behaviour (Grimes & Shull, 2001). The dilution was maintained after changing the mode of reward dispensing as by that stage it was established that it was an effective reinforcer and the dilution lowered the caloric value of the reward, making it safer to dispense repeatedly over long time periods (e.g. two hours) on a regular basis. The sweetened condensed milk solution was made fresh daily. Water was freely available within the chamber at all times.

Because Group 2 were housed in the same room as the testing equipment, the operant chamber was situated within a ventilated sound attenuating outer chamber (Isolation Chamber 540 x 440 x 610 mm, Campden Instruments, England) during all procedures to mitigate the influence of vocalisations and other sounds originating from conspecifics in the room.

3.4. Method

The full method design for the pilot study is described below, with a reflection on the development process in section 5. Due to unforeseen constraints, described in section 5, only one rat completed the full protocol (section 5.4).

A cross-over design (Table 2) was selected to evaluate the effects of treatment (monotonous or variable) and session duration on rat behaviour. A cross-over was used to account for individual variation in responses with a small sample size such as the planned pilot using four rats (Suchmacher & Geller, 2012). Each rat completed five test sessions of one treatment over one week, then completed another five test sessions of the other treatment over one week. Within each treatment presentation order (n=2), one rat's test sessions were limited to a maximum duration of 45 minutes and the other's to two hours. Within each test session, the number of discrete trials was determined by the rat's performance: a rat that completed each trial more quickly completed more trials over the session. A trial was defined as one cycle of stimulus presentation-behaviour-reward followed by a fixed inter-trial interval.

Table 2. Cross-over study design. Rats A and B are initially given the monotony (MONO) treatment and changed to the variation (VARI) treatment after five sessions, while rats C and D start on VARI and change to MONO. Session duration refers to testing sessions.

Rat ID	Session duration	Sessions 1 – 5	Sessions 6 – 10
A	45 minutes	MONO	VARI
B	2 hours		
C	45 minutes	VARI	MONO
D	2 hours		

3.4.1. Training procedures – phase 1

Training rats to perform the task was conducted in three phases. All training and testing took place during the light part of the daily light/dark cycle. In the first phase, the rats were trained to associate illumination of the green LED light over the reward bowl with presentation of the food reinforcer (classical conditioning). For this phase the iPad was present but turned off.

Originally, each rat was placed individually in the chamber for 15 minutes every day for five days. During this time the reward light turned on at fixed intervals every 30 seconds and the reward became available immediately. Phase 1 was intended to end after each rat had performed five 15-minute sessions (Laurence et al., 2015). However, using this criterion resulted in the rats reaching the end of phase 1 at varying levels of competency. For example, while the other rats consistently accessed the reward throughout the fifth session, one rat took over eight minutes to access the reward for the first time in that session. To ensure that the rats were able to associate the illumination of the LED light with the presentation of a reward before moving to the second phase of training, the process was refined according to the protocol of Wolf et al. (2014). Daily sessions were changed from having a set duration to having a set number of trials; each session consisted of 30 trials in which a reward was automatically delivered 60 seconds after the rat accessed the last reward. An infra-red beam was installed to fall across the bowl where the reward was dispensed, allowing automatic detection of when the rat accessed the reward. The next reward delivery was only triggered if the rat broke the IR beam by accessing the previous reward. In order to move on to the next phase, rats were required to complete all 30 trials within one hour.

3.4.2. Training procedures – phase 2

In phase two, the rats were trained to touch a stimulus to access a reward (operant conditioning). This was achieved using an automatic shaping procedure that lead into manual shaping. During this phase the iPad was present and turned on to periodically display a stimulus. The stimulus selected for this phase of training was a white rectangle in the centre of a black screen (Figure 7). For the autoshaping procedure, each daily session consisted of 30 trials which were presented for up to one hour. If the rat failed to complete all 30 trials within an hour, the session was terminated. In each trial, the stimulus was presented for 15 seconds and paired with an immediate marker signal (green LED on) and access to the reward which both activated when the stimulus terminated, followed by a 60 second inter-trial interval. With the syringe driver, the reward became available within three seconds, while with the dipper it became available immediately. Delivery of the reward was not contingent on any response from the animal. However, if the animal touched the stimulus with its paw or nose, the stimulus was terminated immediately, and reward delivery was activated regardless of the stimulus duration.

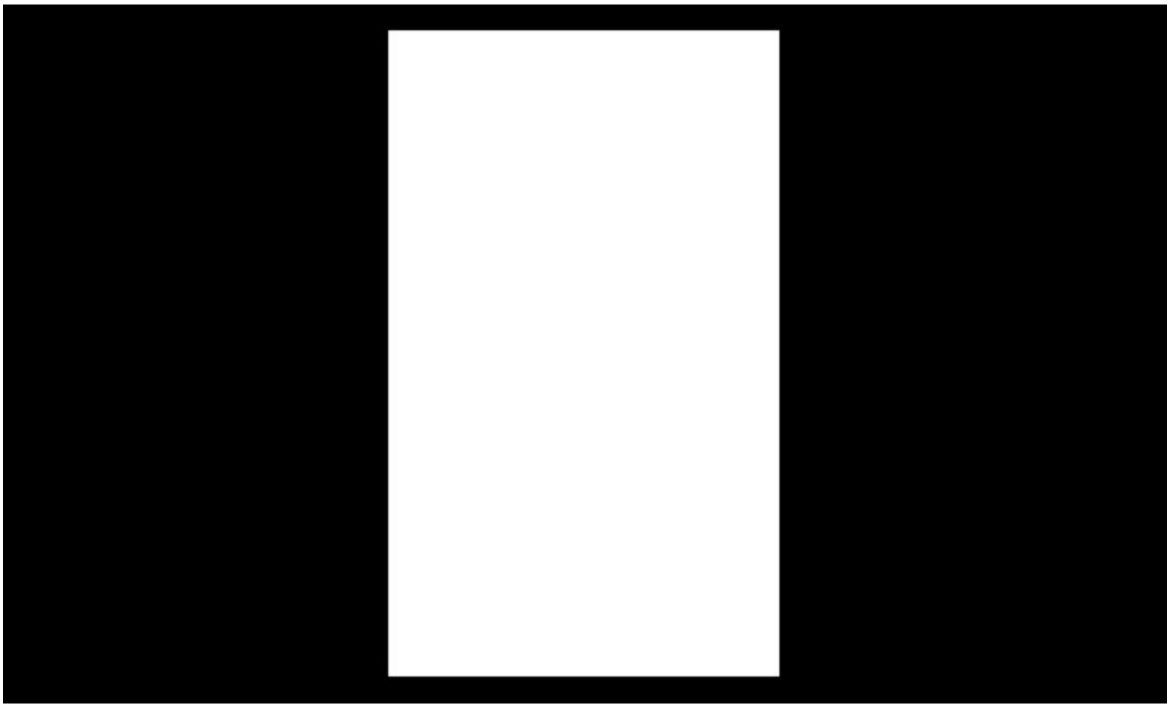

Figure 7. Training stimulus as displayed on touchscreen. The animal can trigger reward delivery by touching anywhere within the white rectangle. This stimulus was kept constant for all rats throughout training phases 2 and 3.

After a single correct press (i.e. touching the screen inside the white square), the rat moved on to manual shaping in which the operator activated the reward process to systematically reinforce successive approximations of the task. This began by reinforcing the rats for pressing the screen of the iPad and over time required them to press closer and closer to the stimulus to gain reinforcement. Controlling this phase manually allowed the operator to assess the responses of each rat and select the criteria for reinforcement trial by trial to ensure that each rat had a high rate of success and continued to progress towards the target behaviour. During the manual shaping phase, the inter-trial interval remained at 60 seconds unless there was no reward triggered. During the trials of Group 3 (section 5.3), it was observed that if the rats were not exploring the screen (i.e. there was no response to the stimulus) when the 60 second waiting time started, they sometimes moved to the opposite end of the chamber and started to groom or sleep. After disengaging in this way, the rats often did not re-engage with the touchscreen for the remainder of the session. Therefore, for Group 4 the inter-trial interval after no response or an incorrect response was reduced to 20 seconds, to encourage the rats to stay engaged in the task. To move on to phase 3, rats were required to correctly press the stimulus on five consecutive trials in each of two consecutive sessions, or ten consecutive trials in a single one hour session (Wolf et al., 2014).

3.4.3. Training procedures – phase 3

In phase three, rats were placed on a continuous reinforcement schedule, meaning that they were automatically rewarded for every correct stimulus press. The duration of stimulus presentation was kept at 15 seconds maximum, and the reward was only dispensed if the rat successfully pressed the stimulus within that time. If the rat failed to complete the task, the stimulus was terminated (i.e. white rectangle disappeared) and the screen left blank for 20 seconds to separate the end of one trial from the beginning of the next trial. If the rat completed the task successfully, the inter-trial interval was 60 seconds. In future iterations of the paradigm, the inter-trial interval should be set to 20 seconds for all trials in this phase. To complete phase 3 and move on to the testing phase, rats were required to successfully complete the task on 90% of trials (27/30) within a single one hour session (Wolf et al., 2014).

3.4.4. Testing procedure

After achieving the phase 3 criterion, rats were randomly assigned to one of two groups: monotony (MONO, n=2) or variation (VARI, n=2). Animals from both groups were initially presented with the training stimulus (a centred white block) followed by the same novel stimulus (a centred white circle). After successfully completing the task with this stimulus once, MONO rats were presented with the same stimulus for repeated trials. VARI rats were presented with a different stimulus for each trial (Figure 8). Alterations to the stimulus included changing its shape, size, colour, or location – for each additional trial only one factor was modified from the previous stimulus presentation. To activate dispensation of the reward, rats were required to press the stimulus with their paw or nose. Rats were rewarded for every correct press, while incorrect presses were ignored. As in phase three of training, the stimulus was presented for a maximum of 15 seconds before a 60 second (correct response) or 20 second (incorrect or no response) inter-trial interval (blank screen).

Within each treatment order group, one of the two rats was exposed to 45-minute sessions and the other to two-hour sessions (Table 2). A session was terminated if 15 minutes passed with no attempts at the task. This was to determine how session duration influences the animals' responses over multiple sessions and to decide on a suitable session duration for the main study.

The rats were tested daily except for weekends. After each rat had completed five sessions (Monday to Friday), the treatment groups were reversed so that the two MONO rats were given task variation and the two VARI rats were given task monotony. After a two day rest, on the following Monday the rats then completed five more sessions under their new treatments, with the duration of each session maintained the same as in the first treatment.

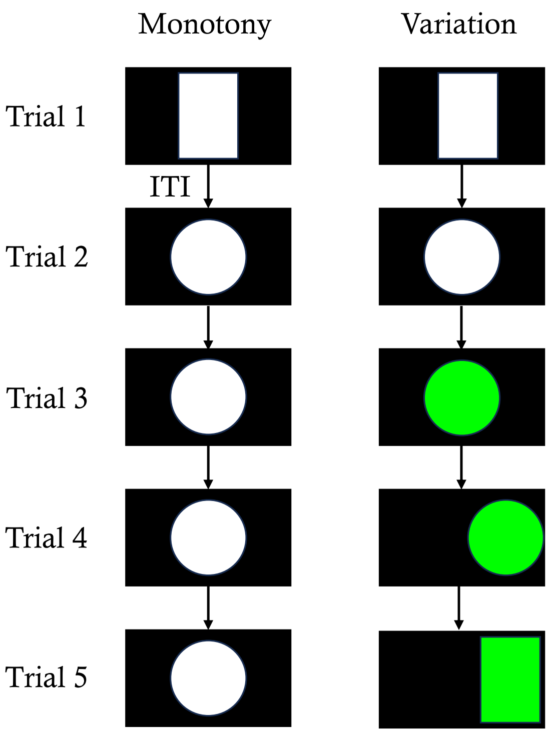

Figure 8. Progression of tasks in successive trials during a testing session for the monotony condition (MONO) and the variation condition (VARI). Changes to stimulus under VARI are indicative only. ITI = inter-trial interval of 60 seconds (correct response) or 20 seconds (incorrect or no response) with a blank screen during which reinforcement is not available.

4. Data collection and analysis

The rats' performance on the task and other behaviours in the chamber were video recorded for later analysis. "Performance" parameters are those related to the performance on the task and are recorded automatically by the Rat Trainer software. They are:

- Time taken from presentation of stimulus on screen to contact touchscreen per trial
- Time taken from presentation of stimulus on screen to contact touchscreen within stimulus per trial
- Number of screen touches (anywhere on screen) per session
- Number of screen touches within target stimulus per session
- Number of times reward dispenser is entered per session
- Number of times reward dispenser is entered whilst reward is available per session
- Total duration of session

A trial was defined as one cycle of stimulus presentation-behaviour-reward followed by a fixed inter-trial interval. A session was defined as the period from when the rat entered the operant chamber until it was removed. Sessions were terminated at the end of the predetermined duration (45 minutes or two hours), or after 15 minutes with no screen touches during stimulus presentation (taken as an attempt at the task).

"Behavioural" parameters are any non-task-related behaviours expressed during the testing session (Table 3). As the purpose of this project was to design and pilot a test paradigm and the sample size was very small (one rat per treatment order and testing duration), no inferential tests were performed.

A key purpose for collecting video data in this paradigm was to assess the occurrence of temporal patterns of behaviour that are indicative of boredom as predicted by the model presented in Chapter 3. Through this lens, behavioural data should be analysed for patterns that reflect cohesive behavioural strategies.

Table 3. Prospective ethogram for analyzing behaviour during the monotony and variation conditions.

Behaviour	**Description**
Grooming	Rat licks or sniffs any part of its own body, or wipes at its own body with its front paws
Scratching	Rat scratches any part of its own body with either its front or back paws
Rearing	Rat sits or stands on haunches, front paws not in contact with floor or walls of the chamber
Wall climbing	Rat sits or stands on haunches with at least one front paw in contact with the walls of the chamber
Sniffing	Rat smells the environment, moving the vibrissae and/or the head (Casarrubea et al., 2019)
Jumping	All four feet leave the ground
Dispenser entry	Rat enters the reward dispenser with either its head or either front paw
Stand climbing	Rat contacts the iPad stand with at least one foot, without touching the iPad screen
Screen touch	Rat contacts the iPad screen with at least one foot
Drinking	Rat places mouth over sipper tube
Resting	Rat sits or lies down and is still, with no limb or head movements, with eyes open
Sleeping	Rat sits or lies down and is still, with no limb or head movements, with eyes closed

5. Outcomes and reflections

The pilot study began in mid-2021 and progressed to being completed in full by one rat. As mentioned above, the development of this study was restricted by a range of obstacles – some predicted and accounted for as far as possible (e.g. COVID-19 related disruptions, technical issues), others unforeseen (e.g. facility problems). This section describes the development process chronologically as the study progressed through the four groups of rats described above, including reflections on my responses to various outcomes.

5.1. Group 1

Beginning on 26/07/21, the first four rats (group 1) began phase 1. All four rats completed five days of the original phase 1 method involving 15-minute sessions (before success criteria were in place). Training was paused here to develop the described refinement, changing from a set session duration to a set number of trials per session and using a success criterion (access the reward 30 times in a single one-hour session). At this point, Aotearoa New Zealand entered a COVID-19 nationwide lockdown (Alert Level 4, August 17 – 31, 2021; Alert Level 3, August 31 – September 7, 2021) and training could not resume. Throughout this period, rats were checked and handled daily but did not enter the operant chamber. After this break in training of 11 weeks, the rats were restarted on 10/10/21 using the refined protocol as described above. All four rats successfully passed the phase 1 training criteria (access the reward 30 times in a single one-hour session) on their first session.

During these sessions (all completed on the same day) a problem was noted with the overhead IR lighting interfering with the IR detector over the food bowl, so training was paused again for troubleshooting. During this pause, the facility in which the rats were housed suffered a power outage which, if sustained, would have put the animals at risk as there was no way to maintain ventilation and temperature settings within the sealed, temperature-controlled room. Due to the potential for welfare compromise in the event of future outages, the rats were immediately removed from the facility and rehomed. Back-up power generators were subsequently installed in the facility.

5.2. Group 2

Due to ongoing delays in the procurement and installation of back-up generators in the original facility, another facility was sought to continue the pilot study. The second group of rats were sourced from within the new facility and started training on 22/08/22. All four rats completed one session of training phase 1. One rat successfully completed the training criterion in the first session. However, during these sessions, it was noted that the IR detector response was still inconsistent despite previous troubleshooting, so entries into the reward dispenser were recorded manually by clicking an "IR break" button in the Rat Trainer software. This button simulated a break in the IR beam over the reward dispenser, so the software recorded the entry and continued its programmed cycle as if the IR sensor was triggered. Two rats successfully completed the phase 1 training criterion in their second session, and one rat required three sessions to reach the criterion. The IR detector problem was solved by refining the sensitivity of the detector to reduce interference from the overhead lighting and lowering the reward bowl, increasing the distance between the IR beam and the bowl to improve the likelihood of a rat breaking the beam with its head (rather than reaching over the location of the beam).

During the first session of phase 2 training, in which the iPad was switched on and displayed a stimulus for the first time, the software did not control the stimulus as expected and the session was terminated. After consultation with the software designer, it was determined that the cause of the software problem was a poor connection between the iPad and the router that connected it wirelessly to the Rat Trainer software. After three rounds of troubleshooting followed by further unsuccessful trials, there was concern about confusing the rats with incomplete sessions or incorrect reward contingencies. Therefore, the training of three rats was paused and troubleshooting continued with only one rat. Over a period of four months, we uncovered and resolved multiple problems with the Rat Trainer software including: browser scrolling when the rat touched the stimulus; poor touch sensitivity for rat feet; and a power supply fault in the syringe driver. However, we were unable to solve the poor connection problem.

In early December 2022 (southern hemisphere summer), I noticed that the rat room was reaching temperatures above the expected and suitable maximum of 27°C. It became apparent that the facility's air conditioning system was not functional. With the aid of fans and increased monitoring, the rat room could be held at a safe ambient temperature and the welfare of the animals was not compromised. However, the planned protocol required rats to go into a wooden chamber (operant chamber) which was held within a larger wooden box (sound attenuating chamber) for up to two hours. Although both chambers had fans for airflow, neither chamber had temperature monitoring capabilities. Due to the potential for welfare compromise at high temperatures, training and troubleshooting was terminated and all four rats were returned to the facility for use in their breeding programme.

5.3. Group 3

By the time training was terminated in the second facility, the back-up power concerns had been resolved in the original facility. Therefore, the equipment was reinstalled in this facility to continue troubleshooting the connection problem. By this point, all of the equipment had been thoroughly checked, and a range of components replaced (e.g. the router) or rewired. The equipment was fully functional when removed from the animal facility but continued to have a delayed or disrupted connection with the iPad when installed in the testing space. The issue was finally resolved by changing the WIFI channel used by the router from the default to a less commonly used channel that did not compete with other WIFI networks.

Two new rats were then sourced to attempt to complete the training phases, and started phase 1 on 24/04/23. One rat completed the criterion for training phase 1 in the first session, while the other rat completed the criterion in the second session. During the first attempt of training phase 2, one rat successfully touched the stimulus, but the software did not recognise the touch and the reward was administered manually. This again raised concerns about the sensitivity of the iPad touch recognition mechanism (capacitive touch) and, in collaboration with the software designer, I began exploring options for different touchscreen technologies. Training was paused to prevent teaching the rats incorrect contingencies.

Training was delayed for three weeks. After consultation with multiple experts and trial development of potential options, we confirmed that due to high costs and availability of technical expertise the iPad technology was still the best choice for our purposes. Thus, we accepted imperfect touch sensitivity as a limitation during the training phases and planned to overcome this with close monitoring and increased manual control during the early stages of stimulus introduction. I proposed that the sensitivity problem related to the fact that the first successful touches were largely accidental as the rat learned the association between the stimulus and subsequent reward and were thus of a light pressure and short duration. It was expected that with further training, the rats could learn to press the stimulus more firmly and that the need to provide the reward manually would diminish.

Training phase 2 was resumed on 18/05/23 with both rats and, within a single session, both animals successfully touched the stimulus at least once, moving them both into the manual shaping stage of phase 2. One rat began to perform a repeating pattern of climbing onto the screen of the iPad and then returning to the reward dispenser. The other rat developed a pattern of climbing the side of the iPad and contacting the screen with a hindleg. However, over the duration of the second phase 2 training session, both rats gradually stopped performing these behaviour patterns and eventually stopped interacting with the iPad at all. The rats repeatedly returned to the reward dispenser, despite no reward being triggered.

After investigation, it became clear that the syringe driver was not able to precisely control the reward delivery – the reward continued to drip irregularly, and the rats were able to access it independently of any planned contingencies. This was not apparent during the first training phase as the reward delivery was not contingent on any response from the rats, so it was not unusual for them to explore the reward dispenser regularly. My initial response was to experiment with different dilutions of the reward with water, in order to thicken the solution and prevent dripping. However, this resulted in the solution becoming too thick to reliably deliver, and the delay between the syringe driver activating and the solution being available was inconsistent. At this point, training was terminated and the rats were rehomed as both had learned the task incorrectly. I then began exploring alternative options for reward delivery.

5.4. Group 4

A lever-arm dipper for reward delivery was purchased and installed into the same location in the original chamber (section 3.3). This reward delivery system was more reliable and faster, meaning that as well as only being available when triggered by the software, the reward could also be made available immediately when triggered, rather than an up to three second wait. With this reward delivery system, the reward itself was kept in a small container under the lever-arm dipper, so that the dipper could move in and out of it. Thus, the reward was open to the air whilst in use. To reduce the chance of the reward becoming sticky and viscous on the lever-arm, a different, less viscous reward was trialled. Rather than diluted sweetened condensed milk, strawberry flavoured milk was used as a reward. This reward had been suggested on multiple occasions by experienced animal technicians and has been shown to successfully reinforce behaviour in rats (Phillips et al., 2017).

Four new rats were sourced with a goal of completing the training phases. The handling and training of these rats was performed by another student under my guidance. Phase 1 training began on 14/11/23. One rat (Ice) passed the training criteria during the first session, however the other three rats did not pass on their first or second sessions. Another rat, Nibbles, only accessed the reward nine (out of a potential 30) times during it's second session. In addition, the rat that did pass and moved onto phase 2 (Ice) stopped responding over two sessions, although the reward dispenser was working correctly. At this point, we suspected that the reward was not highly valued enough. It may be that strawberry milk successfully reinforces behaviour in food restricted rats, but our rats were fed ad-lib. This means that our rats may not have been hungry when they entered the chamber, so the reinforcer needed to be valued enough that they would still be motivated to access it. Due to the success of the previous groups in phase 1, we changed the reward back to diluted sweetened condensed milk. All three rats on phase 1 passed the training criteria in their next session, suggesting that the condensed milk was indeed a more valued reinforcer.

In phase 2, as expected the touch sensitivity of the iPad was inconsistent. After an observation that the touchscreen stopped registering touch after a rat had urinated in the chamber, we began gently wiping the rats' front feet with an alcohol swab before placing them in the chamber. After four sessions involving three individual rats, this did not make an appreciable difference to the proportion of touches that were registered by the Rat Trainer software.

During Phase 2, the protocol was completely automated until the rat successfully touched the stimulus, at which point manual shaping began and the experimenter was able to access full control of the software. However, due to the inconsistency of touch recognition, there were multiple instances in which a rat successfully touched the stimulus but was not rewarded because the touch was not registered by the iPad and therefore did not trigger the response contingency. Therefore, at this point training was paused so the software could be updated. The software was updated to add a "force successful touch" button, allowing the user to trigger the touch-contingent response protocol (i.e. terminate stimulus, deliver reward, start ITI) manually if the iPad screen did not register a correct stimulus touch. Two of the rats (Ice and Sprite) had instances where their touches were not rewarded.

After one, two and three sessions in phase 2 respectively, Ice, Stuart and Sprite developed an unexpected behaviour. After approximately 10 to 15 minutes in the chamber, these rats stopped interacting with the touchscreen and instead sat in front of the reward dispenser until their sessions timed out after 30 trials of stimulus presentation. None of these rats had received a reward for touching the stimulus in previous sessions – Stuart had not yet touched the stimulus while Ice and Sprite had touched the stimulus but not triggered the reward system prior to the software update. This led us to suggest that they had not learned the contingency between stimulus termination and reward delivery using the developed protocol. We addressed this by removing the requirement for rats to successfully contact the stimulus once to move onto manual shaping and instead putting all four rats onto a refined manual shaping protocol (Table 4).

After implementing the refined protocol, three of the four rats progressed to step 5 (touching the stimulus) within three training sessions. Two of these rats (Sprite and Stuart) completed the training phase 2 criteria on their eighth training session after implementing the protocol and the third rat (Nibbles) completed the criteria on the ninth session.

Table 4. Refined manual shaping protocol. Rats were required to successfully touch the required location while the stimulus was displayed on five consecutive trials to move on to the next step.

Step	**Touch location**	**Stimulus presentation**	**Stimulus maximum duration**
1	iPad screen or mount	Immediate after IR break (i.e. reward access)	Until reward triggered manually
2	iPad screen	Immediate after IR break	Until reward triggered manually
3	iPad screen	Five seconds after IR break	Until reward triggered manually
4	iPad screen	Ten seconds after IR break	Until reward triggered manually
5	Within displayed stimulus	Five seconds after IR break	Until reward triggered manually
6	Within displayed stimulus	Ten seconds after IR break	Until reward triggered manually
7	Within displayed stimulus	Ten seconds after IR break	Up to 15 seconds
8	Within displayed stimulus	Twenty seconds after IR break	Up to 15 seconds

One of the rats (Ice) that had learned to monitor the reward dispenser did not progress past step 1 over two training sessions. During the second of these sessions, the rat completed only 5/30 trials. Thus, we further refined the success criteria for this rat by adding an additional step (step 0) before step 1 in which the rat was rewarded upon entering the half of the chamber that contained the iPad. In the proceeding training session, the rat completed 21 trials and progressed to step 3 within a further two training sessions. During the sixth training session after starting step 0, the rat progressed to step 4. However, the rat did not successfully progress further through the protocol from this point.

The planned condition phases (five sessions of monotony and variation conditions respectively) required two weeks to complete, or one week if a rat only completed a single condition. The study was limited to a six-week duration, meaning that the rats needed to complete the training phases within at most five weeks to be included in a single condition phase. Based on the progression during the first four weeks of training, Ice could not successfully complete all of the training phases in time to be included in a treatment phase on the final week. Thus, the rat was removed from the study after four weeks of training on 09/12/24.

Only Stuart completed the training phases in time to progress to the treatment phases. This rat completed five sessions of the variation condition followed by five sessions of the monotony condition. The final session took place on 22/12/24 and all four rats were rehomed on 23/12/24.

With the exception of session durations, the data collected during the monotony and variation sessions were not analysed in time for inclusion in this thesis, and it would be inappropriate to draw conclusions based on a single animal. However, the session duration data from this rat can be cautiously interpreted to inform the pilot objectives. The specific objectives of the pilot study were to:

- Assess the feasibility of task acquisition by Sprague Dawley rats using a touchscreen-enabled operant chamber
- Identify the optimal duration of each session and overall number of sessions required to observe changes in behaviour patterns associated with the occurrence of boredom
- Identify whether gross differences in behaviour and performance patterns are apparent between animals exposed to a monotonous task and animals presented with a varying task when all other features of the paradigm are controlled (i.e. confirm that the two conditions induce sufficiently different degrees of cognitive demand)

The completion of all training and condition phases by Stuart demonstrates that Sprague Dawley rats can acquire the designed task using a touchscreen-enabled operant chamber. Task acquisition was limited by time constraints for the other three rats. As discussed above, two of the rats had instances early in training where they were not rewarded for a correct response. One of these rats did not complete Phase 2 of training while the other stopped progressing during Phase 3. Of the two rats that were consistently rewarded for correct responses, Stuart successfully completed all of the training phases while Nibbles came close to achieving the training phase 3 criteria (twice achieved 26/30 successful touches) before being removed from the study due to time constraints. Therefore, I expect that if the training protocol was repeated with naïve rats using the described refinements, a higher proportion of rats would successfully acquire the task.

In all testing sessions across both conditions, Stuart stopped responding and was removed from the chamber within 45 minutes. This suggests that longer session durations (e.g. two hours as planned) may not be necessary. However, given that only one rat was observed, it is advisable in future to allow for up to two hours per session, continuing the cut-off point used here whereby the session is terminated after 15 minutes with no attempts at the task (i.e. no screen touches). This ensures that rats are not left in the chamber for extended durations unnecessarily but allows for potential individual differences in task persistence.

The overall number of sessions required to observe a difference in behaviour and performance patterns between the two treatments cannot be drawn from the findings presented here. Further analysis of the data collected from the treatment phases may yield preliminary suggestions (e.g. if a specific behaviour pattern develops during the fifth session then an additional session may be indicated to assess whether that pattern perseveres). However, it is advisable not to reduce the number of sessions before identifying specific behavioural parameters of interest and repeating the protocol with a larger number of animals, providing enough statistical power to conclude that a difference in behaviour patterns consistently occurs within fewer than five sessions.

In relation to the third pilot objective, there appeared to be a difference between the session duration in the variation compared to monotony condition, suggesting that the rat tended to stop responding to the stimulus earlier during the monotony condition (Figure 9). This aligns with the predictions of the model presented in Chapter 3, suggesting that the rat stopped attempting to persevere with the task faster in the monotony condition. The significance of the observed difference cannot be determined, so this finding must be interpreted with caution. Despite this, finding this difference between conditions lends support to the premise of the paradigm (i.e. that animals perform patterns of boredom-related behaviour during a monotonous task) and suggests that further development is warranted.

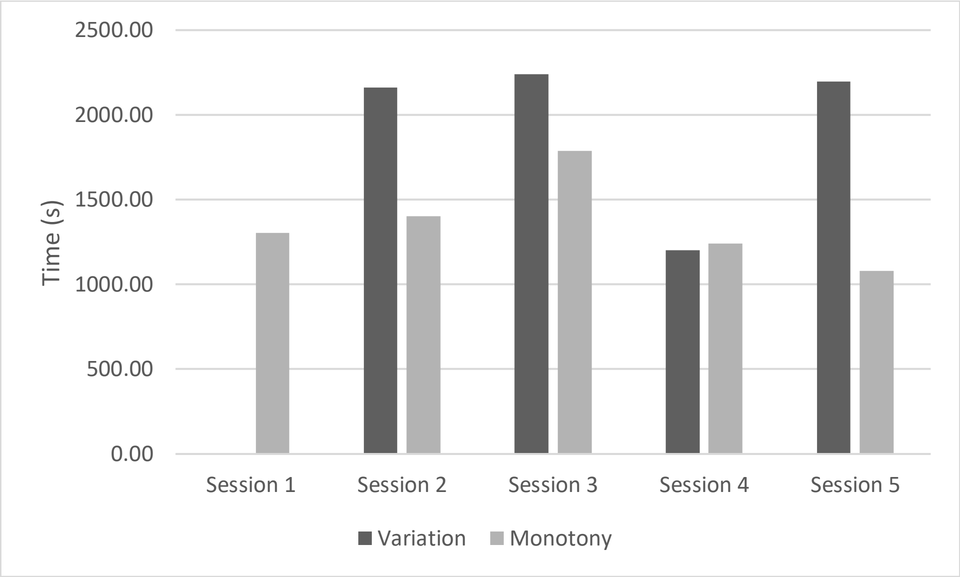

Figure 9. Time to last completed trial before session termination under monotony and variation conditions. The duration of session 1 of the variation condition was not recorded.

5.5. Methodological considerations

During the design, development, and implementation of this pilot study, several features were identified that may have influenced the observation and response of animals during the monotony and variation sessions. These are briefly discussed here to inform further development of the paradigm.

In this study, the operant chamber was sound-isolated from the rats' home environment as far as was practicable. In practice, this meant that rats were moved to a separate temperature-controlled room for training and testing or – where another room was not available – the operant chamber was placed within a sound-attenuating box. This isolation limited the potential influence of any vocalisations or noises made by conspecifics. However, the hardware used to control the chamber (i.e. monitors, keyboards, mouses etc.) had to be installed at close proximity to the chamber (within approx. two metres) so that the wired connections to components on the chamber (e.g. cameras) could reach. Even within the sound-attenuating box, nearby sounds such as keyboard clicks could be picked up by a recording device. Thus, although all practical measures were taken to reduce ambient noise, it is likely that the rats could hear some sounds from the environment including mouse and keyboard clicks used to control the Rat Trainer software. These sounds were present throughout training, so it is possible that the rats habituated to them, which would make it less likely that such sounds influenced the perceived monotony during the MONO condition. However, to improve confidence that ambient noise is not disrupting monotony in the MONO condition, a white noise generator could be installed in the chamber. Noise from mouse and keyboard clicks could also be overcome by using a touchscreen device to control the software.

An important rat behaviour that was not recorded during the pilot study was vocalisation. Rats use a range of different vocalisations for communication, including when under threat and during play (Brudzynski, 2009). Utilising sound recording may capture relevant responses to monotony that would otherwise be lost. Most rat vocalisations occur in the ultrasonic frequency and cannot be heard by humans, but specialised microphones can be used that are designed to record frequencies in the ultrasonic range (e.g. Schwarting et al., 2007). Capturing sound as well as video may provide a more complete profile of behavioural patterns occurring during each session.

When selecting an animal species to use for the development of the paradigm, I also had to decide whether to use animals that were born and raised under laboratory conditions or in the wild. Animals raised in laboratory conditions are likely to have considerably more exposure to monotonous and restrictive conditions compared to their wild counterparts. Given the scarcity of research in this area, there is no evidence to suggest how prior experience of monotony might influence the way that animals respond to the task provided, nor how generations of breeding under monotonous conditions might influence the animals' ability to perceive and/or respond to monotony in the first place. Arguably, laboratory animals could be less sensitive to monotony due to having less experience with environmental change (i.e. have no expectation of change). On the other hand, they may be more sensitive to monotony due to being kept under monotonous conditions for prolonged periods and developing the expectation that monotony is persistent and inescapable. In contrast, wild animals are likely to experience considerably less monotony in their lives and may therefore be less sensitive to it because they have developed the expectation that monotony is controllable or short-lived. Conversely, wild animals may be more sensitive to monotony because they have limited experience with monotonous conditions. Ultimately, given limited guiding evidence and valid arguments for either choice, I chose to use laboratory-raised rats for two reasons. The main reason was for ease and safety of handling, but in addition to this, understanding how laboratory rats respond to monotony is of greater practical application as this information may inform husbandry practices for the millions of laboratory rodents worldwide. Once validated, the paradigm may be useful for understanding how genetic and early-life factors influence the way that animals respond to monotony (Chapter 6), further informing this discussion.

The rats used in the pilot study were fed *ad libitum*. It is common practice when using operant paradigms to restrict the food intake of rodents during the study period in order to increase motivation to perform the operant task (i.e. to earn food) (e.g. Phillips et al., 2017; Tran et al., 2016; Wicks et al., 2017). I chose not to use food restriction for this study for two key reasons. First, I was aware that the training period might be prolonged as I adjusted and refined the protocol and wanted to avoid prolonged food restriction on welfare grounds. Second, I expected that a potential behavioural difference under the monotony condition might be an earlier onset of non-goal-related behaviours (i.e. the rat might stop engaging with the task more quickly under monotony), so did not want to increase hunger which may lead to high task persistence regardless of the task conditions. However, feeding *ad lib* led to its own limitations. The rats in this study were more likely to have stopped responding due to satiety. The risk of satiety was minimised as far as practicable by using a small reward volume and diluting the reward to reduce caloric intake. However, it is possible that rats may still reach satiety under these conditions. This potentially confounding factor was thus also accounted for in the crossover design, with each rat completing both monotony and variation conditions multiple times so that results can be analysed at the intra-individual level. There are two ways in which a rat may stop taking rewards due to satiety. The first is that, compared to other rats, an individual has a lower satiety threshold (i.e. feels full faster). In this case, I would expect the rat to stop taking rewards at a relatively consistent stage in each session, such as after consuming x rewards, regardless of which condition it was in. The second way is that the rat is closer to satiety before entering the chamber (e.g. recently ate or feels less hungry for another reason). In this case, I would expect the rat to stop taking rewards at an earlier stage compared to their other sessions. Satiety can be distinguished from a change in behaviour due to monotony by comparing the response between- and within-subject across the two conditions. A behaviour change due to monotony would have a consistent pattern across sessions within that condition compared to the pattern of that behaviour within the variation condition. Identifying the extent to which satiety occurs requires repeating the protocol with a larger sample size. Further investigation of the influence of satiety could compare the use of reinforcers with varied caloric values, or trial the protocol with feed restrictions in place.

The constraints described above (i.e. ambient noise, no sound recording, use of laboratory strain rats, ad lib feeding) were constant across all of the planned treatment groups (MONO-VARI 45min, MONO-VARI 2hr, VARI-MONO 45min, VARI-MONO 2hr), so they were accepted for the purposes of the pilot. However, it is important that the role of these factors is considered in further development. They represent important questions about factors that may influence how animals perceive and respond to task monotony, and the paradigm itself may be utilised to further understand their respective roles (Chapter 6).

This pilot study initially employed a crossover design in which each animal completes both the monotony and variation conditions. As only one rat completed the training and condition phases, the planned design was not fully utilised. Nonetheless, it is important to consider the impact of this experimental design choice on future development of the paradigm. Crossover designs are a form of repeated measures that are regularly used in biomedical research to examine the effect of medicinal compounds. In such studies, each subject receives a sequence of treatments at different timepoints (Kenward & Jones, 2007). Between treatments, a "washout" period is included to limit the influence of carryover effects, or changes occurring under the first condition, on the observed effects of the second condition (Wang et al., 2016). The washout period is often determined by the half-life of the treatment compound. However, in the current study, the two conditions (monotony and variation) do not consist of the administration of specific compounds, but rather learning from exposure to two different degrees of variation in a trained task. Thus, each condition sets up different learned expectations which may influence subsequent behaviour. For example, if a rat completes the variation treatment first, then it may expect further changes in the task and subsequently persist at the task for longer in the monotony condition than a rat that completed the monotony treatment first. These effects cannot be "washed out" with a rest period between conditions, but they can be accounted for by selecting a study design in which each condition precedes every other condition, including itself, once (Table 5). To identify and account for carryover effects, a strongly balanced design is recommended during the validation process for the paradigm.

Table 5. Example of a balanced crossover design in which each condition precedes every other condition including itself once.

	Period 1	**Period 2**	**Period 3**	**Period 4**
Group 1	MONO	VARI	VARI	MONO
Group 2	VARI	MONO	MONO	VARI
Group 3	MONO	MONO	VARI	VARI
Group 4	VARI	VARI	MONO	MONO

6. Conclusions

The aim of this pilot study was to develop a paradigm for assessing the behavioural responses of animals to a monotonous task. Despite substantial challenges, I was able to progress the development of the paradigm far enough to demonstrate that the task I designed can be learned by Sprague Dawley rats and that at least one gross behavioural difference can be observed between the monotony and variation conditions, which seems to align with the prediction of the behavioural model presented in Chapter 3.

Due to time constraints, I was only able to progress past the training phases of the planned protocol with a single rat. Therefore, I am only able to make preliminary and cautious interpretations about the initial aims of the pilot study. Based on the findings, it seems that five 45-minute task sessions over five days is sufficient to observe a difference in behaviour (specifically duration of task-engagement) between the monotony and variation conditions. I recommend allowing for up to two hours per session to allow for individual differences in persistence. In addition, on average the rat persisted at the task for longer in the variation condition compared to the monotony condition. Although this finding is not empirically valid, it lends support to the design of the task by suggesting that this rat, at least, responded differently to the two conditions. Moving forward, this finding should be empirically tested by applying the paradigm with a larger sample size. Plans for the continued development of the paradigm are discussed further in Chapter 6.

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Chapter 6, General discussion and future directions for the study of monotony and animal boredom

1. General discussion

The purpose of this thesis was to develop the theoretical foundations for understanding how boredom can be investigated in non-human animals kept under human management. This development started with an exploration of boredom as it is currently understood in humans in Chapter 2. Given that boredom is understood to be a subjective experience, in humans it can be assessed via self-report, which is the closest measure available to the true subjective state and therefore the preferred option. In humans, boredom is thought to occur when there is a mismatch between the availability of cognitive resources and environmental demands on those resources, functioning as a signal to switch goals. Understanding boredom in this way supports the developing understanding of boredom in animals by providing potential measures and manipulations that can be used to study the emotion without the use of self-report. The major findings of this exploration were presented in a prospective temporal account of boredom and a novel framework that demonstrates the relationships among proximate features of boredom: the antecedents, correlates, and behavioural outcomes (Figure 1, page 35).

The main value of this framework is for systematically examining the assumptions made in previous animal boredom research to evaluate the strength of the existing evidence and for structuring future research to address knowledge gaps. To this purpose the framework was applied in Chapter 3 to identify correlates of boredom that could be measured in animals. In that chapter, two strategies for manipulating the antecedents of boredom were also presented, namely manipulating the availability of the subject's cognitive resources or manipulating environmental demands on those resources to create a mismatch. This could be achieved, for example, by causing sleep deprivation or reducing environmental complexity respectively. Following from this approach to generating the conditions for boredom to arise, a model was introduced to demonstrate the predicted relationships between the availability of cognitive resources relative to demand, the subject's perceived task meaning and judgement of control, and the observed behavioural outcomes during boredom, should it arise. This model predicts that when there is a mismatch between cognitive resources and demand, and the current task has high meaning to the subject, boredom will lead to attempts to regulate cognitive resources or demand to support persevering towards the current goal, or, if the subject does not perceive their control to be adequate to achieve this, to non-goal-related behaviours. Alternatively, if the current task has low meaning, the model predicts that boredom will lead to attempts to switch goals, or non-goal-related behaviours if control is judged to be low.

Existing animal research, mostly focusing on the effects of environmental complexity (i.e. high restriction leading to low judgement of control) on animals' behaviour, offers evidence that animals housed in barren environments goal-switch when the opportunity is provided. Recognizing goal-perseverance requires the characterization of temporal patterns of behaviour, which are not typically reported in existing studies. Similarly to goal-perseverance behaviours, information about the temporal pattern of non-goal-related behaviours is needed to aid their interpretation. Overall, there is a need for future research to characterize patterns of behavioural change over time rather than capturing intermittent data or collapsing behavioural data during analysis, to facilitate the recognition of the behavioural strategies predicted according to the more structured understanding of boredom as conceptualized here.

Animal boredom is typically discussed in reference to the wider environmental situation, with the term 'monotony' used to characterize spatial complexity or the relative abundance of manipulable and interactive items. In humans, monotony is more often conceptualized as a lack of change over time, but this concept of monotony may not lead to boredom (or even be aversive) in all animals. In accordance, in Chapter 4, monotony (as a lack of change over time) was considered as a potential boredom antecedent. Factors that may influence whether monotony leads to boredom in animals include the type (task, resource, and social) and pattern (unchanging, predictable, or infrequent) of presentation and evolutionary background of the species. For animals that do find monotony aversive, their perception may be influenced by the predictability of change, familiarity with the environment and sources of change, and judgement of control. This information was integrated into the design of an experimental paradigm for evaluating the behavioural responses of rats to task-based monotony.

The touchscreen-facilitated task monotony paradigm (t-fTMP) is designed to manipulate environmental demand on cognitive resources by implementing a highly predictable and familiar task in a restrictive (i.e. low control) environment, leading to a cognitive resource-demand mismatch that is expected to cause boredom according to the model developed in

Chapter 3. The paradigm was piloted with rats, a generalist species that is expected to find monotony aversive, and one animal completed the full paradigm within the available timeframe. This animal stopped responding to the task earlier when it was presented monotonously compared to when the task cue was varied between repetitions (expected to increase cognitive demand). In the context of the boredom model presented in Chapter 3, this may reflect the earlier onset of non-goal-related behaviours such as awake inactivity, indicating that the monotonous task was more likely to elicit boredom, but further analysis of the patterns of behaviour exhibited is required to assess this claim.

The following sections describe future directions for the refinement and application of the t-fTMP and for addressing important knowledge gaps for understanding animal boredom. Because the planned application of the t-fTMP could not be performed within the timeframe of this PhD, section 2 describes the future directions for the paradigm in detail to demonstrate how it fits into the wider context of monotony and animal boredom.

2. Future development and applications for the touchscreen-facilitated task monotony paradigm

The previous chapter demonstrated that rats can be trained to perform the touchscreen task, but some refinement is necessary to improve the functionality of the equipment used. After such refinement, the paradigm could be used to investigate the factors that are predicted to influence behaviour during boredom (i.e. meaning and control).

2.1. Continuing refinement of the paradigm

An important challenge that was faced during the development described in the previous chapter was poor consistency in the touch recognition of the iPad (Chapter 5, section 5.4). Thus, the next step in refinement is the installation of a more reliable touchscreen. iPads use capacitive touchscreens and during the development of the t-fTMP the rats were not able to consistently induce a capacitive change large enough to be registered by the iPad software, which is designed to respond to human-like touch. This resulted in two occasions during training where a rat did not receive a reward for a correct response, and may explain why those rats failed to acquire the task in the available timeframe (Chapter 5, section 5.4). This challenge was not reported in an earlier study that used an iPad with rats (Wolf et al., 2014), but after multiple rounds of troubleshooting and expert consultation (R. Blagojevic, personal communication, March 29, 2023) there were no potential changes or fixes identified that could improve the reliability of the iPad touchscreen.

In future iterations, another type of touchscreen would be expected to improve the function of the Rat Trainer software and allow for a greater degree of automation in the t-fTMP. The most common touchscreen for use with rodents uses an array of infrared (IR) photocells over the surface of a screen that trigger a response when an IR beam is interrupted (Haddad et al., 2021). This means that the animal does not need to exert any pressure on the screen for their touch to be registered, making the touchscreens more reliable and consistent at registering touches (Mar et al., 2013). In recent years these touchscreens have become more accessible and multiple biomedical instrumentation companies now supply operant chamber set-ups with IR touchscreens for rodents.

Once the equipment is functioning adequately, the t-fTMP could be repeated with a larger number of animals. In doing so, statistically significant differences in the behaviour of rats between the monotony and variation treatments could be investigated. At this early stage, the key purpose is to use the paradigm to evaluate the relationship between predicted behavioural patterns and the monotony condition, with a view to understanding whether this condition leads to behavioural patterns indicative of boredom as predicted by the model developed here. With this information, the paradigm can be either further developed or applied to ask other questions about the influence of monotony on animals.

Future iterations of the t-fTMP could manipulate other conditions related to boredom, to investigate how closely the model of boredom-related behaviours developed here predicts behavioural outcomes in this context. For example, judgement of control could be manipulated by providing an opportunity to goal-switch, and further consideration of the operationalisation of meaning for animals may also lead to opportunities to manipulate the meaning of the task. Other manipulations might include sleep deprivation to reduce the availability of cognitive resources, or changes in the predictability and/or familiarity of the stimulus to manipulate the demand on such resources.

If required, the stimuli used in the t-fTMP could be altered to further manipulate demand on cognitive resources. Greater changes between presentations would be expected to increase demand on cognitive resources by increasing the deployment of attention due to a higher degree of novelty and change (Chapter 1, section 2.3.2.1). Features that were varied between trials during piloting were colour (green or white), shape (circle, star, or rectangle), position (left, right, or centre of screen), and size (large or small, excluding rectangle shape), and only one feature was changed between each presentation of the stimulus. The condition was designed this way for simplicity, so the rats could generalise their training to the altered stimuli. The rat tested in the pilot correctly responded to the varied stimuli from the first time a change was presented, suggesting that she was able to readily generalise the trained response to an altered stimulus, so a greater degree of variation should be feasible for use with rats.

Updating the variation treatment might involve changing more than one feature between presentations, adding additional alternatives for each feature (e.g. another colour), or adding more complex alternatives for each feature. In other touchscreen paradigms, rats have been trained to discriminate symbols such as a flower shape and a spider shape, and photographic stimuli (Bussey et al., 2008). The use of more complex symbols would increase the probability that they would be perceived as varied, increasing environmental demand relative to cognitive resources and reducing the likelihood of boredom developing.

Another alternative that was built into the Rat Trainer software but not used in the pilot is the option to animate the stimulus by having it move around the screen. Animation was not used because a moving stimulus may introduce a perceived change in the behaviour required for the task, as it could prompt chasing. To limit conflation of the effects of monotony in the task cue with monotony in the operant behaviour, the use of animation or other strategies that introduce changes to the required behaviour should only be implemented if increasing cue variation alone is not sufficient to increase demand on cognitive resources such that boredom-related behaviours occur less frequently in the variation treatment.

2.2. Potential applications of the paradigm

The t-fTMP could be applied to ask a range of important questions about task-monotony as an antecedent to boredom, including questions about animal welfare impacts, physiological correlates and individual factors influencing animals' responses. For animal welfare scientists, the most immediate question is how task-monotony impacts welfare. The overarching purpose of the development of the t-fTMP was to examine the impact of monotony on animal welfare and identify the occurrence of boredom-related behavioural patterns. If animals respond differently to a monotonous condition compared to a varied condition then this suggests that they perceive monotony, but if the observed behaviours do not align with the expected boredom-related patterns, then it is not necessarily clear whether their welfare is compromised under the monotonous condition. A key behavioural indicator for whether monotony leads to compromised welfare is whether an animal is motivated to avoid or escape from a monotonous situation, suggesting that they experience unpleasant feelings in that situation (i.e. that they find monotony aversive; Chapter 4). To evaluate this, the monotonous condition of the t-fTMP could be applied in a series of other behavioural tests that further assess whether animals find task monotony aversive.

Aversion tests are a type of behavioural paradigm that are frequently used in animal welfare science to assess whether animals are motivated to avoid or escape from a particular stimulus (Kirkden & Pajor, 2006). Types of tests that are used to assess aversion include single-motivation operant tests (Kirkden & Pajor, 2006), approach avoidance (Kirkden et al., 2008), and conditioned place avoidance (Wong et al., 2014). The monotony treatment from the t-fTMP could be used to train an animal to expect monotony in a specific location, to then assess conditioned place aversion.

So far the discussion has focussed on behavioural responses to task monotony. This is because behaviour can be observed non-invasively, so was a preferable metric during the development of the t-fTMP. Further research could also investigate the physiological changes that may correlate with task monotony, however, this depends in part on improved definition and temporal measures of physiological variables in human studies of boredom to indicate the expected changes in animals. Although changes in the activity of the autonomic nervous system during boredom are not yet well understood in humans, monotony during driving tasks is associated with physiological changes such as decreased heart rate (Zhao & Rong, 2013). The monotony experienced in driving tasks involves aspects of low spatial complexity as well as task monotony, both of which would be expected to reduce demand relative to cognitive resources, and such findings lend support to the idea that exposure to monotony leads to physiological responses, at least in the cardiovascular system.

In addition, features related to wakefulness can be measured via EEG, and may contribute to understanding changes related to perception of monotony and boredom. Physiological and EEG parameters could be measured telemetrically in the t-fTMP. Implanted telemetry devices are available for rodents (Chang et al., 2011), and less invasive physiological telemetry devices are available for mammals large enough to safely wear equipment (e.g. in a jacket; Fares et al., 2022). Such devices would allow the animal to move freely about the operant chamber and interact with the touchscreen whilst measuring parameters such as respiratory rate, heart rate, and blood pressure. As with behaviour, patterns of physiological and EEG activity over time are likely to be more informative than single or collapsed measures. For example, rather than a consistent decrease in, for example, heart rate over time, I would expect to observe fluctuations that correlate with behavioural changes such as attempts at goal-switching (e.g. exploratory behaviours). Correspondingly, continuous measurement is recommended rather than intermittent sampling to capture the full time-course of changes during testing.

Finally, the t-fTMP could also be applied to investigate how individual animal factors influence their perception of, and responses to, task monotony. The influence of such factors is not currently well understood (Chapter 5, section 5.5). Thus, the responses of subjects used in the development of the t-fTMP may have been influenced by factors such as their rearing environment or genetic background. However, if the t-fTMP is validated in a laboratory species, then it can be applied to investigate the role of factors including developmental environment, husbandry conditions, individual traits (e.g. boredom proneness), and genetics. Applying the t-fTMP for such investigations would involve identifying groups of animals representing the factor of interest and comparing their relative responses under the monotony and variation conditions.

Information gained from assessing the influence of individual factors on responses to task monotony could inform decisions about the design of animal housing, sourcing or breeding of animals, and training practices in a range of industries. For example, if a particular breed of dog is more averse to task monotony compared to others, then trainers working with that breed could develop training programmes that utilise a higher degree of variation. On the other hand, if a particular species is not sensitive to task monotony or does not find it aversive, then that species might be better suited for contexts in which a higher degree of task monotony is present (such as in unavoidably restrictive situations like being housed in an apartment or zoo). This kind of information could also provide insights for the development of husbandry and management practices that promote better welfare under monotonous conditions by indicating the best strategy for varying the availability of resources and understanding of which resources to vary for a given species.

2.2.1. Considerations for the application of the t-fTMP

The paradigm developed here is intended to provide a practical starting place for investigating how animals perceive and respond to monotony. The t-fTMP was designed specifically to assess responses to task monotony. A limited body of evidence suggests that at least some mammals prefer variety over monotony in some resource categories (e.g. dietary variety; Chapter 4), but animals may not respond to all monotony in the same way. Although monotony was examined here as an antecedent of boredom and was expected to result in boredom-related behavioural patterns, there may not be a characteristic profile of response to monotony of different kinds. Caution is therefore advised when generalising results from the t-fTMP to monotony of different types or presented in different contexts.

Similarly, the t-fTMP may require adaptation if it is used in other species. The paradigm has only been piloted with a single species, which was specifically selected due to an expectation that rats, as generalist mammals, are theoretically likely to have evolved to experience boredom when exposed to monotony (Chapters 1, 4 and 5). Other species, particularly those with highly specialised niches, may not respond to some or any forms of monotony, or may interpret and respond to monotony differently. Highly specialised animals rely upon a high degree of monotony in certain resources for survival. It is therefore important to exercise caution when generalising any responses to task monotony observed in rats within the t-fTMP to other species. It is possible that adapting the t-fTMP for a range of different species could reveal patterns that refine our understanding of the evolutionary factors that influence how animals respond to task monotony – such as resource categories that are more or less likely to be perceived as aversive when monotonous for certain groups of animals. Until such a body of literature is available, ideally the t-fTMP should be adapted for and applied to each species of concern.

3. Developing understanding of the interaction between monotony and restriction in the environments of animals

The degree of restriction in monotonous conditions may have a strong impact on how monotony impacts the welfare of animals in those conditions. In situations where animals are likely to experience boredom, the degree of restriction determines their ability to alleviate it through goal-switching or goal-perseverance behaviours. Providing opportunities for control (i.e. less restriction) results in more opportunities for animals to make choices about the goals that they pursue and the tasks they perform in that pursuit, meaning they are more able to alleviate boredom even if their choices do not change over time.

The impact of restriction on animals is increasingly well considered in animal welfare science. In most animal-management systems, it is not feasible to remove restrictions entirely, but understanding how and when perceived control can be safely and effectively provided to animals has the potential to lead to important welfare intervention and enhancement strategies. The exploration of concepts related to restriction is gaining traction in animal welfare science (e.g. Decker et al., 2023; Englund, 2023; Littlewood et al., 2023; Špinka, 2019), but as monotony often occurs as a result of restriction, it would be beneficial to also draw focus to the effect of change (or lack thereof) on animal welfare outcomes.

4. Future directions for animal boredom research

The investigation of animal boredom presented in Chapter 3 revealed a number of areas for further research. Measures of correlates of boredom that could be developed include task paradigms for assessing executive attention and cognitive over- or underload that do not resolve the antecedents of boredom (restriction and monotony), measures of wakeful arousal in animals, and an operationalisation of meaning that is relevant to animals. Sleep deprivation is a manipulation of cognitive resources that would be expected to increase the likelihood of boredom in animals by creating a mismatch with environmental demand, and future investigations might also manipulate task difficulty or time perception and assess outcomes related to boredom.

The most promising area for future investigations of boredom is the characterisation of behavioural patterns related to goal-switching, goal-perseverance, and non-goal-related behaviour in different contexts. Recognising when or if these patterns occur in animals would support the development of welfare enhancement strategies that allow animals to alleviate boredom in the situations where it occurs.

5. Conclusions

After further refinement and validation, the t-fTMP could be applied to better understand how task monotony impacts the welfare of different species, what behavioural and physiological responses are associated with perception of task monotony, and what individual factors influence these responses. In turn, this improved understanding of the effects of task monotony would be expected to contribute to a wider investigation of how animals respond to other presentations of monotony by providing a point of comparison that could facilitate the identification of any characteristic response profiles, including those indicative of boredom.

Environments that are restrictive and monotonous lead to boredom in humans. Thus, an improved understanding of monotony could also be integrated with ongoing research related to animal restriction and their judgement of control, to better understand how these environmental antecedents impact animals and whether boredom in animals is a widespread occurrence. The research presented here reveals a range of opportunities for future research examining the occurrence and prevention of boredom in animals.

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Appendix A

Littlewood, K. E., Heslop, M. V., & Cobb, M. L. (2023). The agency domain and behavioral interactions: Assessing positive animal welfare using the Five Domains Model. *Frontiers in Veterinary Science*, *10*.

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In which chapter is the manuscript/published work?	Appendix A

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The agency domain and behavioral interactions: assessing positive animal welfare using the Five Domains Model

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Animal welfare denotes how an animal experiences their life. It represents the overall mental experiences of an animal and is a subjective concept that cannot be directly measured. Instead, welfare indicators are used to cautiously infer mental experiences from resource provisions, management factors, and animal-based measures. The Five Domains Model is a holistic and structured framework for collating these indicators and assessing animal welfare. Contemporary approaches to animal welfare management consider how animals can be given opportunities to have positive experiences. However, the uncertainty surrounding positive mental experiences that can be inferred has resulted in risk-averse animal welfare scientists returning to the relative safety of positivism. This has meant that aspects of positive welfare are often referred to as animal 'wants'. Agency is a concept that straddles the positivist-affective divide and represents a way forward for discussions about positive welfare. Agency is the capacity of individual animals to engage in voluntary, self-generated, and goal-directed behavior that they are motivated to perform. Discrete positive emotions are cautiously inferred from these agentic experiences based on available knowledge about the animal's motivation for engaging in the behavior. Competence-building agency can be used to evaluate the potential for positive welfare and is represented by the Behavioral Interactions domain of the Five Domains Model. In 2020, The Model was updated to, amongst other things, include consideration of human-animal interactions. The most important aspect of this update was the renaming of Domain 4 from "Behavior" to "Behavioral Interactions" and the additional detail added to allow this domain's purpose to be clearly understood to represent an animal's opportunities to exercise agency. We illustrate how the Behavioral Interactions domain of The Model can be used to assess animals' competence-building agency and positive welfare. In this article, we use the examples of sugar gliders housed in captivity and greyhounds that race to illustrate how the agentic qualities of choice, control, and challenge can be used to assess opportunities for animals to exercise agency and experience positive affective engagement.

KEYWORDS

agency, animal welfare, positive animal welfare, positive affective engagement, quality of life, good life, happiness, animal wellbeing

1. Introduction

Animal welfare is both an academic discipline and a property of sentient animals. Animal welfare has been described as multidisciplinary (1); however, it is increasingly becoming a transdisciplinary field as it draws from and interacts across disciplines such as animal welfare science (including neurophysiology, applied ethology, and animal science), animal ethics (including philosophy and bioethics), psychology (including beliefs and attitudes, social psychology, and human behavior change), education, communication, animal law, and policy.

As a property of sentient animals, animal welfare represents how an animal experiences their life. Animal welfare, in this context, is a state within an animal. There are myriad definitions used to express this sentiment. However, the most consistently important concept for an animal is a focus on its subjective mental experiences. These mental experiences can vary from positive (e.g., pleasure from a comfortable environment, companionship from conspecifics, feeling well-fed) to negative (e.g., discomfort due to thermal extremes, loneliness, and a feeling of thirst) and can change over time (2). Added to this understanding that mental experiences matter to an animal, those mental experiences hold ethical relevance to the people who interact with animals (3, 4). Mental experiences underpin many animal laws [e.g., (5, 6)] that focus on preventing unnecessary or unreasonable suffering (i.e., suffering is a catch-all term for a range of negative mental experiences). A methodology for assessing animal welfare that focuses on an animal's mental experience is increasingly considered best practice in contemporary animal welfare science (1). This way of assessing animal welfare also creates unity within the discipline by aligning with the experiential focus of other facets (i.e., ethics, policy, and laws). In this article, an animal's *welfare* refers to its overall mental (affective) experiences.

This way of understanding animal welfare can pose challenges when it comes to welfare assessment. Most importantly, mental experiences are felt by the individual animal – they are subjective – and cannot be directly measured. This can be difficult for those accustomed to measuring other quantifiable features of animals, such as reproductive success, body weight, or heart-rate variability. Scientists can find that stepping over Dawkins' 'bridge' from the measurable and observable to the inferential and deducible makes them confront long-held beliefs and values (e.g., positivism) inherent in science [e.g., (2–4)]. However, affective neuroscience and studies in applied ethology allow us to make cautious inferences about relationships between measurable features of animals and their subjective mental experiences (7–13).

Animal welfare, conceptualized as the mental experiences of animals, can also make inferences about positive welfare challenging (14). Given that "good" animal welfare represents an overall positive welfare state, or a good life, for an animal (i.e., when opportunities for animals to have predominantly positive mental experiences are provided), how can positive welfare be assessed in a scientifically robust manner? We propose that the way forward is to consider animal agency.

Agency represents the new frontier in animal welfare assurance. While traditional animal welfare management has focused almost exclusively on minimizing animal welfare compromise, or "suffering," contemporary approaches consider how animals can be given opportunities to experience positive welfare (3, 14–17). For example, standards of care have historically focused on security and physical health aspects of animal housing environments. Guidelines for dairy cattle specify, "Cattle without shelter need to put more energy into normal functioning and less into production" (18). Whereas modern standards now include additional consideration for the positive mental experience of animals, with provisions relating to bedding, cleaning, lighting, temperature, noise, ventilation, and humidity [e.g., (19)]. This is to ensure that animals do not only avoid discomforts that may be harmful but will be comfortable. More recently, positive animal welfare has been characterized by four features: positive emotions; positive affective engagement; quality of life; and happiness (14). We argue that each of these features can be linked to animal agency. More specifically, these features are more likely to occur when animals engage with opportunities to exercise agency.

Agency is the capacity of animals to engage in voluntary, self-generated, and goal-directed behavior that they are motivated to perform (20, 21). These behaviors can be motivated by positive affective consequences (22, 23). The collective term for these positive subjective mental experiences (or affects) resulting from reward-based motivations is "positive affective engagement" (23–25). This term reflects the engagement, or "flow," inherent in these experiences (26). Animals are pleasantly occupied [e.g., a detection dog engaged in a scenting task (26, 27)] to such an extent that they can become oblivious to other sensations or mental experiences – provided they are not significantly negative (23–26). Discrete positive emotions, or affective states, are cautiously inferred from these agentic experiences based on available knowledge about the animal's motivation for engaging in the behavior. Such motivations can be encoded at the species level and passed to the individual animal via their genome (phylogenetic) or occur at the individual animal level because of environmental interactions within the individual's lifetime (ontogenetic). The exact nature of these drivers and their impact on affective experiences are, as yet, poorly understood.

For this reason, positive welfare, or more precisely, the uncertainty surrounding mental (affective) experiences that can be inferred, has resulted in risk-averse animal welfare scientists returning to the relative safety of positivism. This has meant that aspects of positive welfare are often referred to as animal "wants" – and "needs" are the basic provisions that precede these "wants" (28–32). Framing animal welfare as "needs" and "wants" risks reducing human responsibility towards animals to solely neutralizing negative experiences ("needs"), while positive experiences ("wants") could be perceived as an optional luxury (33, 34). Agency is a concept that straddles the positivist-affective divide and represents a way forward for productive discussions about positive animal welfare and to help advance the welfare of animals under human care.

This article aims to articulate how agency can be used to assess animal welfare and the relationship between an animal's welfare and their ability to exercise agency. A secondary objective is to illustrate how the Behavioral Interactions domain (Domain 4) of the Five Domains Model represents this expression of agency.

2. The Five Domains Model and animal welfare assessment

When understood in affective state terms (i.e., a focus on mental experiences), animal welfare should be assessed in such terms (1). The

Five Domains Model is a framework for assessing animal welfare that focuses on subjective mental experiences that matter to the animal (35). Other animal welfare assessment frameworks exist. For example, Welfare Quality focuses on four areas: good feeding, good housing, good health, and appropriate behavior (36). However, none focus on the mental experiences of animals to the same extent as the Five Domains Model (35).

The structure of the Five Domains Model is illustrated in Figure 1. The first four domains represent inputs to the animal that are processed by their species-specific physiology and behavioral biology resulting in physical/functional states (Domains 1 to 3) or representing an animal's externally perceived situation (Domain 4) (35).

Domain 1 (Nutrition) and Domain 3 (Health) are the physical/functional states of the animal (e.g., nutritional or hydration status and physical health issues such as illness and physical dysfunction) that are the states most familiar to veterinary and animal scientists (37). Domain 2 (Physical Environment) focuses on conditions available to the animal (e.g., space allowance, air quality, bedding). Domain 4 (Behavioral Interactions) represents the animal's ability to exercise agency in their interactions with the environment, other animals, and humans (35).

The Model is a framework and focusing device for animal welfare assessment that needs to be operationalized for the specific context and animal The Model is used to assess (38). Valid welfare indicators need to be established for each of the states/conditions/agency initiatives in Domains 1 to 4. The second part of this two-step process requires that these welfare indicators be validated for the specific mental experience they can infer in Domain 5, Mental State (39).

Domain 5 (Mental State) represents the animal's overall welfare, or lived experience, in affective terms (35). This domain is not assessed separately, but rather it reminds users to draw affective inferences from states/conditions/agency initiatives identified in Domains 1 to 4. In this way, The Model takes an affective state approach to animal welfare assessment (35). Welfare impacts identified in Domains 1 to 4 must have corresponding mental experiences (inferred in Domain 5) that matter to the animal to impact their welfare (35).

Evidence from multiple disciplines (e.g., affective neuroscience, physiology, ethology, psychology) informs The Model's use and subsequent updates. In 2020, The Model was updated to, amongst other things, include consideration of human-animal interactions (35). The most important aspect of this update was the renaming of Domain 4 from "Behavior" to "Behavioral Interactions" and the additional detail added to this domain to allow its purpose to be more clearly understood. This domain had been understood by its authors as "The Agency Domain" for several years preceding this update. However, 2020 marked the year where there was a recognized need for Domain 4 to be renamed to link it more explicitly to an animal's ability to exercise agency (35). It was envisaged that this update would help readers better understand Domain 4 and the important role of animal agency in animal welfare assessment (15).

3. Behavioral interactions and domain alignment

Renaming Domain 4 of The Model to "Behavioral Interactions" (35) in 2020 was necessary to align it with the "input" focus of Domains 1 to 3. Domain 1, Nutrition, focuses on nutritional inputs (e.g., food and water provision) that may impact the animal's nutritional status in functional terms. Domain 2, Physical Environment, inputs are externally available conditions in the physical environment (e.g., ambient temperature, air quality). Domain 3, Health, is used for factors contributing to vitality, disease, injury, or other functional or physiological conditions contributing to an animal's physical health and fitness (e.g., parasite control, vaccination). Overall, Domains 1 to 3 focus users on various survival-related inputs and provide a structured approach to inferring how these inputs, and their effects on physical/functional states or available conditions, impact overall welfare (mental experiences) in Domain 5, Mental State (35).

Before the 2020 update, Domain 4 was called "Behavior" and was routinely used to describe an animal's outward behavioral expression. However, behavior is an indicator of welfare. Behaviors can be used across all four domains (e.g., shade-seeking behavior may be used in Domain 2 to evaluate the suitability of the Physical Environment an animal is kept within). The updated term 'Behavioral Interactions'

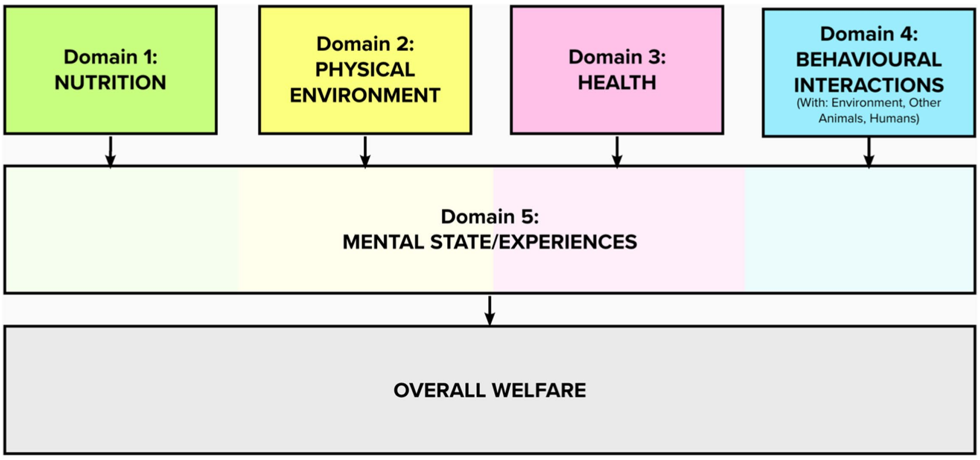


FIGURE 1
The 2020 Five Domains Model of animal welfare.

focuses on inputs to the animal that constrain or provide opportunities for animals to exercise agency (40). Three subcategories were included to encourage users to consider opportunities for animals to exercise agency during interactions with: (A) the environment; (B) other animals; and (C) humans (35).

Domain 2 was also renamed in 2020 from "Environment" to "Physical Environment" to clarify and help distinguish it from Domain 4 (35). Domain 2 focuses on provisions and aspects of the environment that contribute to an animal's physical comfort. In contrast, Domain 4 (specifically the subcategory of 'interactions with the environment') focuses on parts of the environment an animal interacts with and the ways an animal interacts with these features (35).

3.1. Environmental enrichment

Behavioral Interactions (Domain 4) is where environmental enrichment is considered (35, 37) within the Five Domains Model. Environmental enrichment refers to structures and stimuli that promote species-specific behavior that is important and beneficial from the perspective of an individual (41). This means that environmental enrichment broadly corresponds to features that give animals opportunities to exercise agency. Different types of enrichment have been articulated: occupational, physical, sensory, nutritional, and social (42). However, environmental enrichment can be difficult to apply when aligned with the Five Domains Model and the affective state orientation to animal welfare. Firstly, enrichment types are not all 'environmental' in their application. Occupational enrichment can result from interactions animals have with other animals, humans, or even smart technologies (43). Social enrichment, by definition, occurs during interactions with other animals and humans. When using Domain 4, it may be more beneficial to align enrichment types with the different sub-categories of this domain: Environment, Other Animals, and Humans (Table 1).

Operationalizing the term "enrichment" can be challenging. Environmental enrichment originated in laboratory animal welfare as a compensatory device but has become an increasingly essential tool for providing animals in managed captive settings with opportunities for positive welfare (44–46). Environmental enrichment is now used across zoos and aquaria (44, 47) and is increasingly reported in other settings (e.g., farm animals with enrichment opportunities such as brushes and showers). Environmental enrichment has undoubtedly led to improved animal welfare (48). However, it may have reached a point where the term 'enrichment' no longer aligns with contemporary animal welfare science thinking.

TABLE 1 Types of environmental enrichment (42) and their alignment with sub-categories of Domain 4.

Enrichment aligned as behavioral interactions with…		
The Environment	**Other animals**	**Humans**
Occupational, e.g., cognitive (puzzles, activities), exercise (mechanical, run) Physical, e.g., enclosure (size, complexity), accessories (items) Sensory, e.g., visual (windows), auditory (vocalizations), olfactory Nutritional, e.g., delivery (frequency, schedule), type (novel, variety)	Occupational, e.g., cognitive (group activities), exercise Social, e.g., contact (conspecific/non-conspecific), non-contact (visual, auditory, olfactory)	Occupational, e.g., psychological (training activities), exercise Social, e.g., contact, non-contact (visual, auditory, olfactory)

Enrichment implies an optional improvement that can be used in any setting to improve animal welfare. However, animals experiencing significantly negative mental experiences, for example, those raised in isolated and barren environments that do not provide agentic opportunity for social and exploratory behaviors, may be unable to respond to environmental enrichment features [e.g., captive bottlenose dolphins isolated in quarantine did not engage with enrichment toys (49)] (15). Enrichment cannot be treated as a panacea for all issues of welfare compromise or to legitimize housing animals in unsuitable conditions. Instead, there is a need to assess an animal's welfare systematically and holistically across multiple domains to understand the best way(s) to optimize their welfare. For this reason, a more appropriate way forward may be to rephrase this concept as 'environmental optimisation' or 'environmental challenge' (21). Optimisation is more nuanced and implies a greater understanding of the underlying animal welfare compromise and the targeted strategies that should be developed to ameliorate it and bring about welfare improvement.

As a term, *environmental enrichment* has become synonymous with welfare improvement and is entrenched in many people's minds. Thus, reframing its meaning may be a more effective way forward rather than changing the term. Fernandez argues that environmental enrichment was never meant solely to provide animals with *objects. Instead, it* refers to stimuli and/or events that result in animals having opportunities for enriched *quality of interactions* with their environment, other animals, and humans (50). Positive reinforcement training can modify these interactions and function as an enrichment [e.g., training promoted social interactions by moderating chimpanzee aggression during feeding (51)] (50). This framing aligns with the concept of agency and the interaction subcategories of Domain 4. The structured framework of The Model can be used to identify specific enriching interactions and then direct carefully considered and targeted interventions (35).

4. The agency domain and animal welfare

Agency is the capacity of animals to engage in voluntary, self-generated, and goal-directed behavior that they are motivated to perform (20, 21). These behaviors can be motivated by positive affective consequences, i.e., those that result in positive affective engagement, or by negative affective consequences (e.g., avoiding predation or other situations perceived as a threat) (7, 8, 52). Špinka describes three ways to understand the welfare benefits of animals having the capacity for agency: adaptive functioning, affective functioning, and awareness/selfhood (52). From the adaptive point of view, goal-directed behavior confers a survival advantage to animals. An animal that approaches interactions (with its environment, other animals, and/or humans) reactively or reflexively [e.g., the starfish has a righting reflex in response to inversion (53)] is less likely to survive in complex environments than one that has the cognitive capacity to be proactive (flexible) in its interactions (52). For example, wild deer fawns with mothers who proactively hid their young were more likely to survive in open habitats than reactive-mothered fawns (54). Conversely, expressing agency may be less critical to animals in simple environments with relatively stable interactions.

The affective functioning viewpoint focuses on evidence from affective neuroscience and an appreciation of the neurobiological mechanisms underpinning mental (affective) experiences (52). Fundamental to this viewpoint is the understanding that mental experiences are motivational forces (or drivers) for the complex behaviors animals perform (16). In other words, mental experiences are proximate causes of complex, but not reflexive, behavior (55, 56). More complex agentic capacities require more diverse underlying mental experiences. Animals operating competently within complex environments might be expected to possess a greater range of mental qualities because of a need to exercise greater agency.

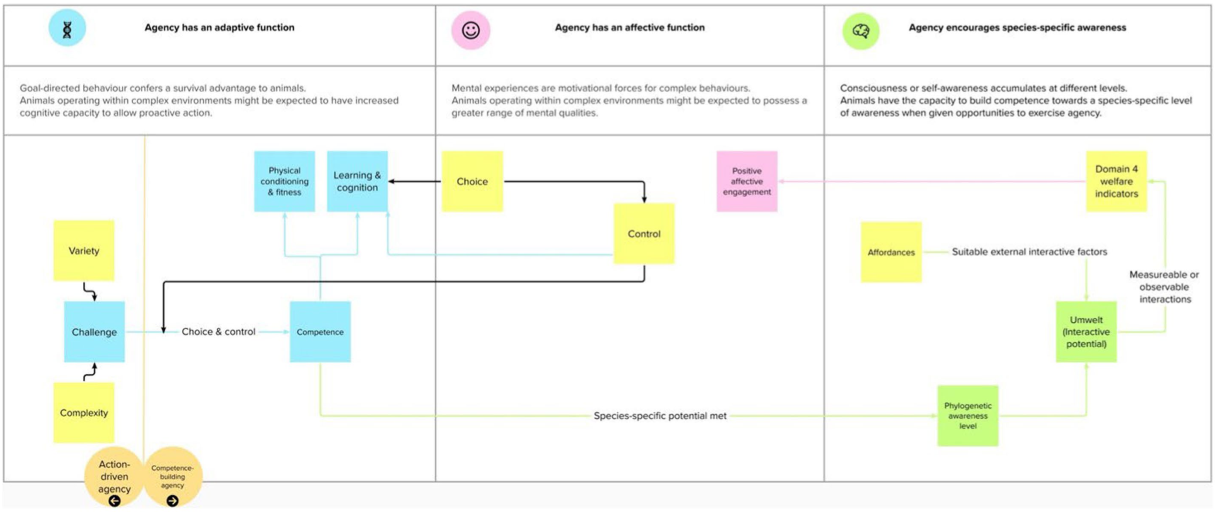
Differing levels of awareness is another way of conceptualizing the welfare benefits of animal agency. In this conceptualisation, consciousness or self-awareness accumulates at different levels (52). The most basic level of awareness includes a sense of 'core self' that allows individuals to identify sensations and behaviors as their own in the present moment (7). The next awareness level relates to competence-building (57). At this level, the animal has the capacity for cognitive processes such as learning and memory, enabling them to accumulate skills and knowledge from previous experiences. In other words, animals can build competence towards a species-specific level of awareness when given opportunities to exercise agency. Long-term goals and aspirations are features of the highest awareness level and result from decision-making based on introspection (52). An animal's umwelt, or unique perceptual world, is dictated by its awareness level (58). Therefore, a higher level of awareness gives a broader scope for umwelt.

Overall, Špinka identifies three ways agency relates to positive animal welfare (52). First, agency can be competence-building, and animals given opportunities to exercise agency are more likely to develop the skills (e.g., physical strength, social cohesion, mental resilience) necessary to overcome future agentic challenges. In other words, animals learn when they can exercise agency. Play in young animals is an example of this agentic learning process (59). Second, animals with opportunities to exercise agency can also experience positive affective engagement (i.e., a range of positive mental experiences), for example, pleasure, affectionate sociability, and care (15, 38). Finally, it is proposed that competence-building is welfare-enhancing as it supports the development of species-specific higher levels of awareness and allows an animal's full interactive potential, and umwelt, to be met (52). At a higher level, this could result in animals, with the phylogenetic capacity, attributing meaning to their lives – a feature used to classify human happiness (52, 60), refer Figure 2.

4.1. Competence

A detailed exploration of agentic qualities such as competency, choice, control, challenge, and umwelt can further articulate agency. Competence results when an animal has the tools and strategies to deal with novel and ongoing challenges (31, 52, 61, 62). In other words, competency is the outcome of animals' opportunities to exercise agency during their lifetime. The strategies for behavioral interactions (with the environment, other animals, and humans) have developed because of these opportunities, i.e., competence is agency-driven ontogenetic development (31, 57). Competence can enable future agency and be an outcome of exercising agency. The characteristics and skills developed during opportunities to exercise agency can enable animals to act with self-determination and increase their opportunities for agency (57).

Enhanced functional (e.g., physical conditioning) and cognitive (i.e., learned) capacities contribute to competence. Lack of space or incentive to exercise vigorously can result in poor physical conditioning, often exacerbated by uniform and limited opportunities for interactions with the environment (63). An individual animal unable to satisfy its genetic (phylogenetic) and developmental



Goal-directed behaviour confers a survival advantage to animals.
Animals operating within complex environments might be expected to have increased cognitive capacity to allow proactive action.

Mental experiences are motivational forces for complex behaviours.
Animals operating within complex environments might be expected to possess a greater range of mental qualities.

Consciousness or self-awareness accumulates at different levels.
Animals have the capacity to build competence towards a species-specific level of awareness when given opportunities to exercise agency.

FIGURE 2
The three ways Špinka (52) relates agency to positive welfare and their relationship to other concepts used in animal welfare science.

(ontogenetic) competence potential may experience a form of learned helplessness (63). Conversely, an animal in a barren environment may have developed less competence and a reduced threshold to perceive novelty (64). This could lead to arguments against providing animals in captivity with environmental enrichment opportunities. However, individuals with low competence living in captive environments should still be provided opportunities to exercise agency.

Suppose environmental enrichment provides opportunities for animals to exercise agency and develop competency. For example, they may become more challenging animals to contain in a zoo setting. In that case, a potential solution is to restrict opportunities for agency (e.g., by withholding enrichment) to limit escalating enrichment requirements. However, agency is required for animals to develop optimal physical functioning (e.g., via play) as well as mental capacities (26, 34, 65). Agency is also self-fulfilling and provides animals with opportunities to experience positive affective engagement in novel ways or ways that cannot otherwise be provided (15, 38). And even with restricted opportunities to exercise agency, and thus blunted competence, many animals retain the pre-programmed genetic potential (i.e., motivation) for agency due to phylogenetic developmental events within their species (31, 65). Impeding agency is in and of itself a welfare compromise, independent of how lowered competency may influence the perception of further welfare-compromising conditions. Ethically, if we are aware of these agentic requirements of animals (i.e., a valid evidence base exists), people are morally obligated to provide them. We anticipate this obligation will feature increasingly in the safeguarding, welfare assurance, standards of care, regulations, and animal management legislation in the coming years.

4.2. Choice

Choosing between two or more options allows animals to exercise agency (52, 57, 61, 63). Agentic "freedom of choice" roughly aligns with one of the Five Freedoms; "freedom to express normal behavior" (66, 67). However, providing for choice requires animals to have uninhibited options that align with their species-specific motivations (68). This requires detailed knowledge of what is normal for a species to do (i.e., knowledge of their behavioral biology). The domestication process has changed the behavioral biology of some animals to such an extent that 'normal' may cease to exist at the species level (3). Comparisons to wild populations cannot always be relied upon as many domesticated species no longer resemble their wild ancestors (3). Also, there is still much to learn about the behavioral biology of a range of taxa (69, 70). Added to this, there can be marked differences in the preferences of individual animals (52, 63).

Consequently, even at the species level, "normal" behavior represents a generalization that may not be informative when assessing the welfare of an individual animal. Overall, these considerations make it difficult to predict the behaviors an animal may want the "freedom to" perform. Affording animals agentic choice offers more versatile options for positive welfare, such as using technologies (40), than providing animals with contexts to perform specific "normal" behaviors – when they are known. Additionally, animals may prefer fewer choices than those offered to them or may prefer to interact with a choice not offered in managed settings.

Active environmental enrichment represents an example of agentic choice. Active enrichment is something an animal engages with directly through agentic choice being provided (e.g., food hidden in a tree to be detected and secured). In contrast, passive enrichment is provided to the animal without agentic choice (e.g., music is played) and may be not be perceived as rewarding by the animal (65, 71).

4.3. Control

Choice and control are interrelated aspects of exercising agency. Control is realized when an animal can *consistently* and *predictably* make choices and obtain the outcomes they are motivated to achieve (61, 65, 72). When animals can actively decide when and how to interact with the environment, other animals, and humans, they have an element of control over their choices (52, 57, 65, 72). Inaction is as essential as action; an animal choosing not to interact (e.g., with a toy offered to it) exerts control over its actions and therefore exercises agency (57, 65). Perception of control, whether exercised or not, influences cognition and behavior in animals responding to challenging situations (62, 65).

Perceived control forms the basis of cooperative care protocols and animal consent (73). Cooperative care involves training animals to make informed choices (i.e., consent) about their management (74). These training protocols should allow animals to consent and withdraw their consent at any time. Chin rest is an example of a common consent behavior used in dogs (74). Informed choice involves some level of predictability (i.e., control) and allows animals to exercise agency by controlling what happens to them (74). For example, automated technology can enable dairy cows to control their engagement with mechanical grooming brushes (75). When an animal can exert control, they may be more likely to engage in challenging interactions and develop competence (65).

4.4. Challenge

Various complex interactions can challenge animals and encourage the development of problem-solving abilities that confer competence (21, 46, 64, 65). Novelty increases the variety of interactions an animal may have. An animal can be provided with difficulty by making situations or tasks challenging to analyze, understand, or solve such that learning occurs (57, 61). Physical challenges can also offer advantages to animals by improving physical conditioning and fitness (64). Care must be taken to ensure challenges are not too far beyond the competency level of the individual animal as this can have negative affective consequences, e.g., result in frustration or anxiety (64). Suppose these challenges do not far exceed an animal's current competency level (i.e., they are surmountable). In that case, they offer an opportunity for the animal to exercise agency and experience positive affective engagement (15, 38). Examples of so-called 'environmental enrichment' challenges, and their alignment within Behavioral Interactions, Domain 4, are presented in Table 1.

4.5. Umwelt and affordances

How an individual animal feels about its competence also matters for its welfare. An animal's umwelt represents its unique perceptual and effector world, i.e., an animal's inner world (58). A higher level of awareness gives a broader scope for umwelt (52). The concept of umwelt has the added advantage of considering the differences in sensory worlds between animal taxa (58). Umwelt goes beyond sense organ physiology and considers how an animal responds to their situation and how these responses modify their perceptions of self and subsequent interactions with the environment, other animals, and humans (58).

In their discussion of animal communication, Parton and Marler (58) liken umwelt to Gibson's theory of affordances, which describes the relationships between animals and their environments (76). Affordances of the environment are what it offers the animal, good or bad (76). An affordance is measured relative to the animal and is unique to that animal rather than measured in abstract physical properties (e.g., load-bearing force). Because affordance is interpreted relative to the perceiver (76, 77), an animal's unique perceptual world (umwelt) will impact its perceived affordances (58). Gibson (76) suggests that an animal's ecological niche is a set of affordances. A niche is how an animal lives and their role, rather than the habitat or where they live (76). An animal's perceived affordances may determine their ability to develop competence and, in turn, impact how they can exercise agency.

Each of the terms interact to provide an overview of how animals might be provided opportunities to exercise agency to engage in voluntary, self-generated, and goal-directed behaviors that they are motivated to perform (20, 21), as depicted in Figure 2.

5. The agency domain in action: assessing animal welfare

Špinka's four tiers of agency can help further articulate the role of animal competency when using the Five Domains Model to assess animal welfare. These tiers are passive/reactive agency, action-driven agency, competence-building agency, and aspirational agency (52). The tiers are distinguished by the type of behavioral interaction an animal has, which relates to the dominant brain structure(s) and awareness level(s) operating.

Passive/reactive agency is characterized by passive or reflexive reactionary behaviors resulting from external stimuli. Most are driven by homeostatic and sensory affective states involving the brainstem or corresponding neural substrate in non-mammalian animals (52). The resultant drives are probably subconscious and unlikely to play a role in animal welfare and assessment. For example, moon jellyfish (*Aurelia* sp.) dive in response to turbulence (78).

Action-driven agency involves emotional action systems at the subcortical level (52). The resultant behaviors are mostly survival-related, aimed at procuring food, seeking shelter, and avoiding predation. This tier aligns most with Domains 1 to 3 (Nutrition, Physical Environment, and Health) and is not the 'interactive' agency considered in Domain 4 (Behavioral Interactions).

Competence-building agency involves active behavioral interactions to build skills and acquire information for later use. This tier involves learning-related emotions at the level of the basal ganglia or corresponding neural substrate in non-mammalian animals (52). Such activities are future-focused and, rather than achieving immediate outcomes, allow animals to enhance skills and gather information (i.e., develop competence) for future use. Examples include instrumental and social learning, exemplified by contrafreeloading whereby animals choose to work for food over obtaining freely available food (50, 78). Inspective and inquisitive exploration, communication, and some forms of play also fall within this tier (52). This tier most closely aligns with the operational intent of Domain 4 (Behavioral Interactions). In other words, competence-building agency is the construct being assessed when the Behavioral Interactions with the environment, other animals, and people in Domain 4 is used as part of a holistic welfare assessment protocol.

Aspirational agency is driven by an animal's neocortex and allows for complex interactive behaviors resulting from planning and goal setting. These often involve *affectively* guided planning and intentions to act (52). However, the evidence thus far suggests that this agency level is less prominent in non-human animals. Therefore, this level of agency is not currently considered within the Five Domains Model of animal welfare assessment but does encourage debate about how an animal's time perception and planning may be considered in future updates to The Model.

Given the traditional focus of animal welfare science on the biological functioning orientation and alleviating welfare compromise (3, 79), we have amassed substantial information that contributes towards our understanding of negative mental experiences aligned with Nutrition, Physical Environment, and Health, Domains 1 to 3. Behavioral Interactions, represented in Domain 4, and their aligned mental experiences have proven more challenging to study empirically. This most likely stems from the difficulty scientists face when attempting to develop paradigms to evaluate agency robustly. This is particularly true for mental experiences traditionally assigned a positive valence (25, 34). However, as mentioned, we should avoid returning to the relative safety of positivism, where any reference to mental experiences is side-stepped. Instead, these challenges encourage us to exercise extra caution when considering mental experiences aligned with Behavioral Interactions and the expression of agency (Domain 4). Moving forward, animal welfare assessment using Domain 4 could be performed by reflecting on an animal's ability to exercise various qualities of agency (see Section 4 of this paper) and aligning these to the experience of positive affective engagement (a catch-all term for positive mental experiences related to exercising competence-building agency) (15, 38). The terms 'pleasure' or 'happiness' could be used to reflect this when communicating with a lay audience.

5.1. Impediments to agency being exercised

Negative mental experiences inferred from impacts in Behavioral Interactions (Domain 4) result from impediments to an animal's ability to exercise competence-building agency. These negative experiences reflect the cognitive responses of animals to being kept in impoverished environments (e.g., a laboratory rat in experimental deprivation conditions), under firm behavioral restriction (e.g., a working guide dog that cannot actively explore by sniffing or interact with other people or animals it encounters), or confronted by threatening situations (e.g., a horse kept with resource guarding conspecifics). This helps explain why these negative experiences have been collectively termed 'situation-related negative affects'; they reflect the animal's perception of their external circumstances, i.e., their situation (15, 35).

Impoverishment is a feature of restricted opportunities to engage in interactive behaviors – with the environment, other animals, or humans. Examples of these restrictions include limited space, barren or invariant features in enclosures, and social animals with little or no access to the company of others (15, 80). The development of negative mental experiences in restricted circumstances is believed to result from thwarted genetically pre-programmed (phylogenetic) or learned (ontogenetic) motivations to engage in rewarding behaviors or behaviors that result in a reward (7, 8, 15, 21). Such adverse experiences inferred (in Mental Experiences, Domain 5) from restricted circumstances may initially include frustration and fear (e.g., short-term kennelling of dogs) and then give way to boredom, depression, helplessness, loneliness, and isolation (8, 20). These latter mental experiences may promote low activity and energy conservation where resources are limited (81, 82). In other words, these mental experiences may result from loss or lack of reward following unsuccessful attempts to engage in highly motivated behaviors, i.e., when competence-building agency has been impeded.

Interactions (with the environment, other animals, and humans) that are cognitively perceived as threatening are also aligned with Domain 4, consistent with the positive and negative inputs possible in Domains 1–3 (Nutrition, Physical Environment, Health). Examples of potentially threatening situations include possible or actual attack, separation from the security and protection of others of social significance, and overstimulation or being presented with challenges that an animal has not developed competence to manage or avoid (15). Negative experiences inferred (in Domain 5, Mental State) from threatening situations may include anxiety, fear, and panic (8, 15). These negative mental experiences align with Mendl et al.'s upper left quadrant, i.e., Q4 of the functional core affect model, resulting from a desire to avoid aversive situations (81, 82). They promote coordinated responses to the presence of threat or danger. Such experiences are unlikely to be competence-building if the circumstances impede an animal's ability to exercise agency through choice and control (e.g., victimization in a confined space).

5.2. Opportunities to exercise agency

Positive mental experiences inferred from Behavioral Interaction factors in Domain 4 are attributed to animals having opportunities to exercise agency and express more of their behavioral repertoire (15, 35). Correction of impacts in Nutrition, Physical Environment, and Health (Domains 1 to 3) that generate survival-related negative Mental Experiences (Domain 5) may enable the animal to refocus on engaging in rewarding behaviors. In other words, survival-related negative mental experiences at high intensities (i.e., compromised welfare) dominate the overall mental experiences of an animal, but when minimized, allow the animal to exercise agency and experience positive affective engagement (15, 38). This could be akin to an animal experiencing an overall feeling of physical safety when survival-related experiences aligned with Domains 1 to 3 are mitigated (83). Once physically safe, animals are more likely to engage in the rewarding Behavioral Interaction activities of Domain 4 (83).

Short-lived positive experiences may be generated from survival-related behaviors motivated by negative mental experiences (15). Water drinking behavior (Domain 1) initiated by the negative experience of thirst (Domain 5) may also result in transient positive experiences such as oral wetting and quenching pleasure (13). Such positive mental experiences may reduce or replace negative experiences but are unlikely to contribute to an overall positive welfare state long-term (15).

In contrast, some situation-related negative experiences may be replaced by positive ones when improvements are made to interactions (with the environment, other animals, and/or humans) that allow animals to engage in more rewarding behaviors (13, 17). For domestic species kept in human-dependent conditions, the negative experiences generated by such impeded interactions (i.e., impeded agency) often require intentional human intervention to correct. Again, providing opportunities to engage in rewarding behaviors is the basis of environmental enrichment strategies (44). Enrichment initiatives can serve to promote positive mental experiences (15, 38).

As mentioned in section 4.1, negative experiences (e.g., helplessness and isolation) can result from restricted circumstances (81, 82). Interventions to replace these negative experiences with positives (e.g., happy, excited) should focus on providing animals with opportunities to acquire rewarding experiences during their behavioral interactions (with the environment, other animals, and humans) (81, 82). Stimulus-rich and diverse or novel settings allow animals to engage in interactive behaviors, such as exploration and play, associated with positive experiences (15).

Potentially threatening situations can result in negative experiences such as anxiety and fear. These negative mental experiences likely result from a desire to avoid aversive situations (81, 82). However, when opportunities are provided for animals to build competence and exercise agency through choice and control, positive experiences (e.g., calm and relaxed) can replace these negative experiences (81, 82).

The precise valence and intensity of some individual mental experiences are still debated (e.g., boredom, helplessness) and likely vary depending on the individual's life experiences and the length of time they are experiencing these feelings. Further exploration is needed to develop our conceptual understanding of these mental experiences. However, strategies to support agency and positive affective engagement focus on providing animals with opportunities to exercise a maximal 'level of agency'.

6. Strategies to support agency and positive affective engagement

This section gives situational examples where animals can have competence-building agency and experience positive affective engagement. To illustrate this, we use two examples where opportunities for animals to exercise agency could be enhanced: sugar gliders kept as animal companions and greyhound dogs that race and are housed in kennels. Creating such opportunities for animals to exercise agency may require additional resources, such as space, equipment, or people's time.

Assessing the welfare of animals using the Five Domains Model requires a systematic approach using all five domains. When experiences aligned to Domains 1 to 3 (e.g., hunger, pain) are sufficiently negative, animals may be less motivated to engage with opportunities for competence-building agency (84). In other words, without an overall experience of physical safety and health, an animal is less likely to engage in activities they might have found rewarding

(83). However, given that this article focuses on the Behavioral Interactions (Domain 4), an abbreviated approach to identifying potential welfare impacts aligned with Domains 1 to 3 will be taken. This does not detract from the importance of a complete and systematic welfare assessment here; instead, it reflects a desire to focus specifically on elucidating the connections between Domain 4's behavioral interactions with the environment, other animals and people, and positive welfare.

6.1. Sugar gliders housed in captivity as companion animals

Sugar gliders (*Petaurus breviceps* and *P. notatus*) are small, nocturnal, arboreal marsupials, native to parts of Australia and Oceania (38). In the wild, they live in colonies of 10–15 individuals in open forests and have an omnivorous diet of gum, sap, and insects (38, 85). This species spends most of the night active in tree branches and can glide up to 50 meters between trees (38, 85). They are highly active and maintain a territory of up to 1 ha in the wild (38). Although keeping these wild animals is restricted or prohibited in many places, Sugar gliders are an example of a non-domesticated animal commonly kept as companion 'pocket pets' in several countries globally, including the United States (85). They have an average lifespan of 7 years in the wild but can live up to 15 years in captivity (38). They have a paedomorphic appeal that likely triggers an instinctual human attraction – often described as the "baby schema effect" (86). A set of infantile (or neotenous) features, perceived as cute, evoke a nurturing response from humans, i.e., their small size (12 to 15 cm in length), facial features that are large in comparison to their round head, and large, dark, wideset eyes (38, 86). When kept as companions, they often present with veterinary problems associated with inappropriate housing, activity and diet, e.g., obesity (85).

6.1.1. Domains 1 to 3

In captivity, welfare impacts aligned with Domains 1 to 3 are diverse. An inappropriate diet (Domain 1) is a common cause of sugar gliders presented to veterinary clinics (38). Many readily available diets show evidence of mineral and vitamin imbalances (38, 87). Diet-related conditions include malnutrition, obesity, osteodystrophy, and dental disease (38, 87). These will likely lead to mental experiences such as hunger, weakness, malaise, and pain. Sugar gliders tolerate temperatures between 18 and 32°C. Temperatures outside this range increase the risk of them experiencing various forms of discomfort and thermal extremes of chilling or overheating. Having sufficient space for spontaneous locomotion (Domain 2) and maintaining physical fitness (Domain 3) is also essential for positive welfare opportunities in Domain 4.

6.1.2. Domain 4

Examples of positive behavioral interactions aligned with Domain 4 are further sub-categorized into interactions with the environment, other animals, and humans (Table 2).

6.1.2.1. Interactions with the environment

In their natural habitat, sugar gliders are nocturnal and spend much of their awake time at night foraging for food, i.e., interacting with their environment. They use their long incisors to extract gum and strip bark from trees (38). When food is readily provided to captive sugar gliders, this not only increases their risk of developing obesity (Domain 1) but also reduces opportunities for them to perform feeding behaviors that build competence and would otherwise keep them occupied for extended periods (Domain 4) (38). Instead, materials that simulate foraging can be provided in captivity, e.g., holes drilled into non-toxic materials filled with food or other complex food toys (38). These are examples of occupational, physical, and nutritional enrichment strategies (Table 2) that allow sugar gliders to experience positive affective engagement.

Aviaries of sufficient size, particularly height, allow sugar gliders opportunities to glide between perches (38). These animals will also need branches- or rods arranged vertically and horizontally in their enclosure – to encourage scurrying, jumping, climbing, and gliding (38). Perches, swings, and ladders are valuable items in aviaries (38). Items resembling predators (e.g., clothing) should not be left where sugar gliders may perceive them as a threat, e.g., on top of cages, as this might limit their exploration and interaction with the full scope of available environment (38). For resting, a nest box should be provided in a suitably-sized aviary (85).

6.1.2.2. Interactions with other animals

Sugar gliders are vulnerable on the ground and prefer to remain elevated (85). Sugar gliders are often kept individually in small bird cages with a suspended pouch as a nest (85). Sugar gliders in the wild are territorial and can become aggressive if not introduced carefully (85). The social nature of sugar gliders means that most guidelines recommend housing them in groups of at least two in captivity (38). Sugar gliders prefer to sleep huddled together, so nests should be large enough to allow co-habitation (38). Cats and other predatory species should not have access to sugar gliders (38). Although people may perceive sugar gliders as safe within an enclosure, probably, smelling the presence of predatory animals, such as cats, in the same space will impact their mental state and restrict behavior.

6.1.2.3. Interactions with humans

Sugar gliders are nocturnal, so they should be handled at night when most active and not disturbed during daylight hours (38). Hand-reared sugar gliders handled quietly and calmly can develop into gentle companions (38). Scent has a vital role in social recognition in sugar gliders. For this reason, newly introduced and rehomed animals should be given time to recognize their handlers' scents (38).

6.2. Racing greyhounds housed in kennels

Greyhound racing is a sport and gambling industry sector that relies on small groups of greyhounds running competitively out of starting boxes on a racetrack at speeds of around 70 kilometers per hour. The distinct life stages of greyhounds bred to race typically involve breeding, rearing, early education, training, racing, and leaving the industry. However, the industry's practices have been subject to controversies and criticisms in the media and politics, with concerns about dog welfare and the business model's ethics (88, 89). Globally, commercial greyhound racing is declining, remaining legal only in the United Kingdom, Ireland, Vietnam, Mexico, New Zealand and parts of the United States and Australia.

TABLE 2 **Examples of behavioral interactions (Domain 4) that can be provided to, and their utilization assessed in, sugar gliders housed in captivity (with aligned enrichment strategies from Table 1) that enable them to experience positive affective engagement (Domain 5) and their aligned agentic qualities.**

Behavioral interactions	Agentic quality			
	Competence[1]	Choice[2]	Control[3]	Challenge[4]
Interactions with the environment				
A choice of materials[R] that stimulate foraging behaviors[A] (occupational, physical, nutritional)	🟦	🟥	🟩	🟪
Aviaries of sufficient size[R] to allow gliding[A] (occupational, physical)	🟦		🟩	
A range of aviary items[R] to encourage scurrying[A], jumping[A], climbing[A], and gliding[A] (occupational, physical)	🟦	🟥	🟩	🟪
Able to avoid items[R] in or near aviaries that may be perceived as a threat (sensory)	🟦	🟥	🟩	
Interactions with other animals				
Housed in groups of at least two individuals[M] to enable social interactions[A], and resting[A] (occupational, social)	🟦	🟥		🟪
Nests of sufficient size[R] to allow individuals to huddle together[A] (social)	🟦	🟥		
Space[R] and housing design[M] that allows them to avoid[A] social interactions or predators that may be perceived as a threat (social)	🟦	🟥	🟩	🟪
Interactions with humans				
Interactions limited to night-time only[M] (occupational and social)	🟦			🟪
Frequent quiet and calm handling with control over their engagement with the handling[M] (social)	🟦	🟥	🟩	🟪
Slow and controlled introductions to handlers[M] to allow scent identification and familiarisation[A] (social)	🟦		🟩	🟪

Agentic qualities: [1]Characteristics and skills developed through opportunities to exercise agency; [2]Choice between two or more options; [3]Able to decide when and how to interact; [4]A variety of complex interactions that do not exceed an animal's current competency level. Types of animal welfare indicators: [R]Resource-based welfare indicators; [M]Management-based welfare indicators; [A]Animal-based welfare indicators.

Practices across life stages tend to follow the same general model. Pups are born and stay with their mothers until weaned. By 12 weeks, they enter the rearing phase, which may occur in a paddock, kennel or barn environment. During this stage, they are often housed with some littermates. They enter early education schooling at approximately 1 year as the starting point for training and chasing. They enter residential kennels where they are housed individually and participate in training, trials, and sometimes sales or amateur racing before starting professional racing around 15 months of age. Dogs continue to live in residential kennels until they exit the racing industry, usually by 5 years old, if not before. They may leave racing due to injury or death on the racetrack, being retired, rehomed as a companion, or transitioning to a breeding role.

One of the main controversies surrounding greyhound racing, aside from the high rate of injuries and deaths on the track (88, 90), is the inadequate housing conditions and lack of compensatory environmental enrichment. Another issue raised is the inadequate socialization of puppies which impacts their ability to adapt as companions in new homes later in life, along with the apparent overbreeding and euthanasia or unknown fate of dogs considered surplus, known as *wastage* (91).

Overall, the controversies and criticisms surrounding greyhound racing have contributed to growing public awareness and scrutiny of the industry internationally. This has increased pressure on regulators, stakeholders, and industry insiders to address the welfare and ethical issues raised and consider alternative models for managing and caring for greyhounds in the sport.

6.2.1. Domains 1 to 3

Greyhounds that race have increased nutritional demands (Domain 1). Nutrition should balance protein, fat, carbohydrate (including fiber), and vitamins. Protein is essential to support muscle use and growth. Extreme physical exertion likewise predisposes these dogs to dehydration (Domain 1). Inappropriate nutrition and hydration can lead to negative affective consequences such as thirst, hunger, weakness, and malaise of malnutrition. Appropriate hydration (Domain 1) is also necessary to control body temperature *via* panting (Domain 2). Systemic hyperthermia can result from exertion, hot environments, or an inability to cool effectively. Preventative health care is critical to optimize greyhound welfare (Domain 3). Disease prevention includes routine vaccination and parasite control. Training and racing intensity should match a dog's current physical competence level. This means consideration should be given to maintaining training during downtimes or rehabilitative training following recovery from injury/illness. The critical importance of racetrack-related environmental features (e.g., kennel facilities and catch pen design) and appropriate pre-race warm-up activities to reduce the incidence of injury are reportedly overlooked during race meets (92, 93).

6.2.2. Domain 4

Greyhounds that race spend a relatively brief period of their time budget running in one to two weekly races. Even if training, travel, handling, and kennelling are factored in, much of their time is spent outside engaging in racing-related activities. To counter the potential for boredom or frustration in the intervening time and to build competence (94), greyhounds should be provided with opportunities to exercise agency. Examples of opportunities for positive welfare aligned with Domain 4 are further sub-categorized into interactions with the environment, other animals, and humans (Table 3).

6.2.2.1. Interactions with the environment

Designated spaces provided beyond the primary housing or kennel facility can allow greyhounds to explore and interact with their surroundings. Outdoor areas featuring a diversity of elements and substrates (e.g., grass, sand, trees, gravel, etc.) facilitate physical activities that promote fitness and allow for the expression of social (e.g., turning and jumping while engaged in social play) and other behaviors (e.g., digging) (95). Indoor spaces can be provided to preview the home environment (e.g., appliances and furniture) that retired dogs should transition to, allowing dogs to navigate and adapt to different challenges and settings that will set them up to succeed as competent animal companions beyond their time in racing (96).

Within their primary housing and transportation containment, sufficient space for easy stretching, lying down in full extension, and turning around should be ensured. This will enable greyhounds control to move comfortably. Providing multiple resting areas (e.g., elevated resting platforms and beds at ground level) allows dogs to choose how they utilize the space available to them (97). These provisions enable them to adjust their body positions, express their preferences, and exercise agency. Greyhounds may reposition bedding material to their liking, another way to exercise control. Providing more space to greyhounds promotes movement, reducing the likelihood they will experience affects such as frustration or discomfort. However, increased space alone is unlikely to offer sufficient agentic opportunities for positive welfare (98).

Interactive sensory stations can be provided in both indoor and outdoor spaces. These feature various scents, textures and objects for greyhounds to investigate and safely interact with. Based on their individual preferences and curiosity, such stations offer the dogs a choice as to what they engage with. Additional opportunities for positive experiences can come from devices such as puzzle toys and treat-dispensing toys, which engage greyhounds in challenge, both physically and cognitively (99). The complexity of spaces, objects, sensory stations and other novel objects should be gradually increased to support the animals' agentic choice and control to support the development of competence.

6.2.2.2. Interactions with other animals

Facilitating supervised interactions with other dogs allows greyhounds to develop and engage in appropriate social behaviors and establish positive social connections. Social connections provide opportunities for positive experiences through companionship, social bonding, and play (100–102). These experiences can also provide the greyhounds with exercise and a sense of comfort and security, promoting relaxation. Social housing, where compatible dogs live in pairs or small groups, facilitates social interactions. One way this can be achieved in a kennel facility is by enabling access between adjoining kennel runs so that multiple dogs can choose to be together or separate. Adequate space to comfortably accommodate the pair or group of dogs must be available in any kennel run if this strategy for shared housing is adopted.

Historically, greyhounds that race have been identified as having relatively poor socialization practices (103, 104). This can be related to isolated rearing occurring in rural locations and limited resourcing for active practices to adequately compensate. Social interactions with various other dogs help puppies learn and develop appropriate social and communication skills with conspecifics (105). Play groups that

TABLE 3 **Examples of behavioral interactions (Domain 4) that can be provided to, and their utilisaton assessed in, racing greyhounds housed in kennels (with aligned enrichment strategies from Table 1) that enable them to experience positive affective engagement (Domain 5) and their aligned agentic qualities.**

Behavioral interactions	Agentic quality			
	Competence[1]	Choice[2]	Control[3]	Challenge[4]
Interactions with the environment				
Sufficient space[R] to encourage free movement and play[A]	🟦	🟥	🟩	🟪
Varied sensory inputs[R, e.g.,] nosework (olfactory-based sniffing activities[AM])	🟦	🟥		🟪
Socialization and habituation[M] to common household environmental stimuli[R] to prepare for future rehoming as companion animals	🟦	🟥	🟩	🟪
Interactions with other animals				
Access[M] to congenial relationships with other dogs, e.g., the choice[A] to live in pairs; regular play time[M] in small groups with compatible individuals	🟦	🟥		🟪
Able to avoid threatening situations[A, e.g.,] sufficient space[R] and responsive monitoring[M] for threat avoidance	🟦	🟥	🟩	
Socialization[M] and habituation to other animals	🟦	🟥	🟩	🟪
Interactions with humans				
Reward-based training[M]	🟦	🟥	🟩	🟪
Positive interactions[M] with a variety of people[R]	🟦		🟩	🟪

Agentic qualities: [1]Characteristics and skills developed through opportunities to exercise agency; [2]Choice between two or more options; [3]Able to decide when and how to interact; [4]A variety of complex interactions that do not exceed an animal's current competency level. Types of animal welfare indicators: [R]Resource-based welfare indicators; [M]Management-based welfare indicators; [A]Animal-based welfare indicators.

allow greyhounds to interact with other dogs of various breeds, sizes, ages and temperaments will expand their social skills' flexibility (i.e., competence) in response to dogs they meet throughout their life.

Positive experiences with other animals, both large and small, allow dogs to learn how to interact appropriately with different animals (106). This further develops their social skills and competence in multi-species environments, which is particularly relevant for successful rehoming following racing. Opportunities to interact with other animals can be provided with appropriate supervision and choice. In this way, individual dogs can exercise their agency, approaching and engaging with other animals (e.g., meeting a horse through a fence while on lead). Allowing greyhounds to learn to relate socially with other animals in a supportive manner is a challenge that can contribute to their overall competence. Foster programs in private homes (i.e., as often undertaken in working dog programs such as detection or guide dog rearing) during puppyhood and throughout the time a greyhound is racing may provide essential respite from the kennel environment (107) and alternative experiences to interact with a variety of animals and people (108, 109).

6.2.2.3. Interactions with humans

Ensuring that interactions with people, such as grooming and play sessions, are positive for greyhounds builds trust and promotes healthy attachment between the dogs and their caregivers (110, 111). For example, interactive play sessions between people and greyhounds can be undertaken using toys, agility equipment, or flirt poles. Such sessions enable the dogs to exercise choice in initiating and controlling their level of engagement while also challenging them physically and cognitively, promoting competence. Positive reinforcement training should form the basis of all foundational interactions between humans and greyhounds (112, 113).

Training activities can offer both cognitive and physical challenges relating to learning new behaviors, problem-solving, and overcoming obstacles of increasing complexity. With experience, this builds canine confidence in interacting with people, and their competence can increase. Dogs learn through every interaction that their behaviors directly influence the outcomes they receive, providing the individual animal with control in their training exercises. Greyhounds should be granted the choice to actively opt-out of training sessions if they do not wish to engage in the behaviors or with the equipment that will earn them rewards, providing them with control over their actions. Providing greyhounds with individual attention from people also allows for personalized interaction and the development of positive social bonds. This also facilitates the personalisation of training and care practices in a manner that can safeguard against fear, anxiety, or frustration.

It is important that greyhounds who race are able to meet a variety of people during puppyhood and their time in racing (114, 115). This include people of different ages, heights, appearances, and sex. Facilitating good socialization and ongoing experiences with a diversity of people allows greyhounds to interact positively (competently) with humans during and after their time in racing, a desirable trait for dogs.

6.3. Supporting agency and positive affective engagement

The two scenarios presented above are not intended to be exhaustive representations of how opportunities for agency could be supported in each. Instead, they have been used to illustrate how animals can be given opportunities to exercise agency in various contexts. Choice, control, and challenge represent agentic qualities that appropriate human care can provide, while competence likely results from these opportunities. Conversely, umwelt and affordances are agentic qualities not directly impacted by human care – so they have not been included in Tables 2, 3. They represent an animal's unique perceptual and effector world (umwelt) and their perception of what their environment offers them (affordances). Umwelt, affordances, and competence represent agentic qualities that need further exploration to identify potentially relevant positive welfare indicators.

While our evaluation of negative impacts in Domains 1 to 3 for each case study scenario focused on the potential mental experiences that might be inferred from conditions in each domain (e.g., hunger, weakness, and pain), this was not the case for Domain 4 (Behavioral Interactions) and positive welfare. Instead, we found it more beneficial to evaluate opportunities for agency to be exercised by considering agentic qualities of choice, control, and challenge that could be provided to the animal(s). In essence, we evaluated features of positive affective engagement (i.e., the collective term) rather than specific named positive mental experiences. This approach provides a means of systematically evaluating options to provide animals with opportunities to exercise agency. It may also help risk-averse animal welfare scientists cross the positivist-affective divide.

One flaw with our approach to evaluating positive welfare is that many behavioral interactions in our two scenarios mapped across similar or identical agentic qualities (Tables 2, 3). Therefore, detailed comparisons between interactions might be challenging to perform. An alternative approach might involve some indication of how strongly each agentic quality is exercised by a behavioral interaction being offered or occurring for the animal(s). For example, a behavioral interaction might offer an animal the ability to exercise a high level of choice, low control, and moderate challenge (Table 4). This behavioral interaction could then be compared against the agentic qualities of another interaction and this comparison might allow us to account for the interests of an individual animal or species. A non-numerical score could also be assigned to indicate how confident the rater is in assigning the strengths of these agentic qualities to the behavioral interaction (Table 4), i.e., to indicate the strength of the evidence used to assign the agentic score (116, 117).

Competence has not been included in Table 4 as this was the agentic quality that mapped across most behavioral interactions in our scenarios. The agentic qualities of choice, control, and challenge represent opportunities for agency that can be provided by human

TABLE 4 Opportunities for positive interactions (Domain 4) can be provided to an animal, and their utilization assessed so that the animal's experience of positive affective engagement (Domain 5) can be inferred.

Behavioral interactions	Agentic quality		
	Choice	Control	Challenge
Example behavioral interaction	🟩 **	🟥 ***	🟨 *

The agentic qualities have been color-coded for each behavioral interaction being assessed. These colors represent how strongly each quality is exercised by the behavioral interaction being offered or occurring (e.g., green = high; yellow = moderate; red = low). Asterisk(s) could be used to indicate the degree of confidence a rater has in assigning the color code for each agentic quality – from low (*) to high (***).

care and management decisions, while competence is the potential result of these opportunities. Therefore, including competence did not provide additional information beyond that provided by the other three agentic qualities. However, future iterations could see competence included with sub-categories of physical and cognitive/mental competence to distinguish the types of competence that might result from each behavioral interaction (26, 34, 65).

In the two scenarios presented above, we have focused on opportunities for positive behavioral interactions. There is also scope to assess how well animals utilize these opportunities (15). An animal can be given opportunities to exercise agency (i.e., human care and management). Still, the animal's actual utilization of these opportunities determines whether or not they experience positive affective engagement (i.e., positive animal welfare). The approach in Table 4 might be used as a staged evaluation, where Stage 1 involves identifying opportunities for behavioral interactions, and Stage 2 is where the animal's utilization is assessed (15). However, animal utilization might be challenging to assess given that a lack of 'utilization' does not imply agency is not being exercised, i.e., an animal not interacting with an opportunity provided to them is still exercising agency through choice and control (57, 65). This area of evaluation and continuous improvement in offering greater agentic opportunities to animals under human care and management is an important consideration for future focus.

Future consideration should also be given to best practice communication with stakeholders (e.g., animal caretakers, industry bodies, regulators, policymakers, and the general public) about agency and positive animal welfare (118, 119). Translating theoretical and research findings to meaningful change for animals under human care often depends upon effective communication and subsequent human behavior change.

7. Conclusion

Animal welfare is a complex and multi-disciplinary field that encompasses the subjective mental experiences of animals. Focusing on mental experiences is becoming increasingly important in contemporary animal welfare science, as it aligns with other aspects of safeguarding and animal welfare assurance, such as ethics, policy, and laws. However, assessing animal welfare based on mental experiences can pose challenges, as they are subjective and cannot be directly measured. The concept of agency represents a new frontier in animal welfare assurance, as it allows us to consider how animals can be given opportunities to experience positive welfare by engaging in voluntary, self-generated, and goal-directed behavior that they are motivated to perform. This article argues that agency is a concept that straddles the positivist-affective divide and represents a way forward for discussions about and opportunities for positive animal welfare. Understanding the relationship between an animal's welfare and their ability to exercise agency can be illustrated through Domain 4 (Behavioral Interactions) of the Five Domains Model. Overall, the concept of agency provides a promising approach to understanding and improving the welfare of animals.

Author contributions

KL: Conceptualization, Writing – original draft, Writing – review & editing. MH: Conceptualization, Writing – review & editing. MC: Conceptualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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