Aalborg University Copenhagen

Aalborg University Copenhagen
A.C. Meyers Vænge 15, 2450
Copenhagen SV, Denmark

Secretary: Lisbeth Nykjær
Phone: 9940 2470
lny@create.aau.dk

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Supervisor(s): Luis Emilio Bruni

Project group no.: 101

Members:

Sebastian Alberdi Eriksen (20180576)
Thomas Anthony Pedersen (20181224)
Tilde Højgård Jensen (20153098)
Vladislav Zenkevich (20181231)

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The study showed possibility for identifying activity of the Hindsight/Foresight Feedback-loop using pupil dilation, as we found a tendency of increase in pupil dilation over time in a narrative point of interest, indicated by the participants through interviews.

However further research and testing is needed in order to confirm the indications found in this study, as this study is to be considered a pilot study, and thus exploratory in nature.

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Hindsight/Foresight Feedback-loop

An exploration of hindsight and foresight, using psycho-physiological measurements in an interactive narrative

Medialogy master thesis, Spring semester 2020

Eriksen, Sebastian Alberdi
`student no. 20180576`

Jensen, Tilde Højgård
`student no. 20153098`

Pedersen, Thomas Anthony
`student no. 20181224`

Zenkevich, Vladislav
`student no. 20181231`

September 1, 2020

Contents

Disclaimer: We use the terms reader, consumer, user, viewer, participant etc. interchangeably throughout the report, as labels for "a person experiencing a narrative" no matter the medium through which this is experienced.

1 Foreword

This thesis took inspiration from the international RHUMBO project, which investigates the implicit brain processes related to decision-making, by "using measures of subconscious brain processes through the use of mixed reality technologies (MRT) and advanced biometric signals processing"[83]. As such, this exploratory pilot-study seeks to assist in creating some potential groundwork for RHUMBO, which is also visible in the results section, where the results of this study should be regarded as initial findings, indicative of a direction for future works, as per design from the onset.

Hence, the end-goal of this study was to explore the possibility for determining indications of hindsight and foresight, through the use of psycho-physiological measurements.

Covid-19 pandemic

This thesis, was initiated in the spring semester of 2020, which was right before the covid-19 pandemic of 2020, as well as worked on throughout the pandemic. Because of this, testing was done on a much smaller scale than what was originally desired, as we would be using Virtual reality, which would be mounted on the participants. Safety was deemed a high priority, we therefore opted for a smaller sample size, and we sanitized the headset and controllers between each participant - and we asked the participants to use hand sanitize before touching the equipment. Test conductors were also using hand sanitize between participants as well as keeping a safe distance. One test conductor would get close to the participants when helping with the equipment.
Besides testing suffering greatly from this extraordinary event, laboratory access was also restricted for several months, though this is not an excuse in any way, rather just a factual statement for posterity's sake.

2 Abstract

This study explores the cognitive processes of hindsight and foresight through the use of interactive narratives and the psycho-physiological measurement of pupil dilation. Through an extensive literature review of hindsight and foresight, from both a cognitive as well as narratological standpoint, we propose a framework (the Hindsight/Foresight Feedback-loop) to characterize the workings of hindsight and foresight and their connection to memory. The study further seeks to detect activity of this framework in an interactive narrative in virtual reality, using measurements of pupil dilation. The study showed possibility for identifying activity of the Hindsight/Foresight Feedback-loop using pupil dilation, as we

found a tendency of increase in pupil dilation over time in a narrative point of interest, indicated by the participants through interviews.

However further research and testing is needed in order to confirm the indications found in this study, as this study is to be considered a pilot study, and thus exploratory in nature.

3 Introduction

With an onset in cognitive science and narratology, this study explores the relation between hindsight and foresight in interactive narratives in virtual reality. Hindsight and foresight can be regarded as crucial elements in the processing and understanding of any narrative, with an origin in our own evolutionary survival, in the form of expectancy and adaptation to a changing and uncertain future[6, 77].

Therefore, one of the main pillars for this study's claim to existence is best said by Thomas Suddendorf:

> *"[T]he ability to imagine future events seems to be an essential part of human cognition since much of our behaviors are guided by foresight (e.g., distant goals or plans)"* [54, p.209]

However, as we "cannot construct a sound vision of the future without rooting it in the past" [28, p.88], there seems to be a close connection between hindsight and foresight. It is this exact phenomena, the imagination of future events based on prior experiences, which this study seeks to explore.

As humans we constantly reorganize and expand our knowledge, and are able to create future scenarios in our mind,in order to analyze possible outcomes to aid in decision making[77]. Thus, after an event have taken place, we analyze and reflect upon these experiences and the new knowledge gained. Related to this, it can be argued that this way of processing experience and memories is closely related to (if not the same as) how narratives are organized and constructed in our minds[50, 15, 68, 3]. As such, this study seeks to combine narratological and cognitive theories with psycho-physiological approaches to examine foresight and hindsight both as a phenomenon, and as measurable cognitive processes.

Hence, this study seeks to characterize hindsight and foresight in relation to memory and narratives. We will therefore utilize an interactive narrative of our own design, in order to investigate the cognitive processes of hindsight and foresight, by exploring the potential of using psycho-physiological measurements to detect this cognitive behavior.

Initial problem-statement: *How can hindsight/foresight be characterized using interactive narratives in virtual reality?*

4 Analysis

Before the onset of this project, we find it pertinent to elaborate on our most basic premises. Our ontological and epistemological viewpoints. This project relies heavily on the propositions of narratology and cognitive science. Whereas we seek to investigate the cognitive responses in the brain, which happens when one experience foresight and/or hindsight during a narrative. Initially foresight and hindsight will be defined from a narratological standpoint, and as such how they are used in a narrative - written as well as through mixed media. Foresight and hindsight are both, by their very nature, linked to memory, hence the workings of the human memory will be taken into account as well, in order to understand how foresight and hindsight works cognitively.

4.1 Foresight/Hindsight

One of the primary elements used in decision-making, both strategically for businesses and in everyday life, is the use of foresight. The ability to reason about the consequences of a given action/decision; i.e. to be able to predict "[..] the future consequences of behavior in the past and the present" [52, p.174]. Foresight has even been argued to be a key survival strategy evolved in humans [76]. As such, we are constantly faced in the present with situations requiring us to make decisions in which we utilize foresight as the catalyst for the action. Some so deeply rooted in us, that we make the decisions subconsciously, without thinking about it, and others so complex, that we consciously and strategically analyze the potential outcomes before making the decision [44, 56]. Nevertheless, no matter if a decision is as simple as the opening of a door (We predict, that by turning the handle the door will open), or as complex as trying to decide what loan to get in a bank, *foresight* is utilized [44].

Foresight has been argued to be intrinsically linked to hindsight [52, 44, 76]. While it has been argued that we "cannot construct a sound vision of the future without rooting it in the past" [28, p.88], it is even suggested that the simultaneous handling of information of past, present and future is a prerequisite for consciousness. Within this dynamic perception of the tripartite of time into past, present and future, it has been argued that "[o]ur thought moves both backward and forward, while time moves forward [..]" and "[w]hen we retrospectively re-configure our past by endowing past experience with new meaning, we re-configure our future as well" [48, p.646](Originally claimed by Mark Freeman[33, p.190]). As we continuously - to the best of our abilities - try to predict the future, we rely on what we know of the past. This information in our memory can both be actual personal experiences, as well as ideologies and culture that is being taught rather than experienced [52]. Neuroscience defines these as *episodic memory* and *semantic memory*. Episodic memory is understood as personal memories in each persons life, specific in time and place, whereas semantic memory is regarded as "conceptually based knowledge about the world" [89, p.203]. These two types of memory are defined as *Declarative memory* and their neurological and cognitive workings, will be further expanded upon in section 4.2.

As stated previously, it has been argued, that when we employ the cognitive process of foresight, we are utilizing hindsight in the present to inform our prediction of the future. In other words, the process of foresight can be described as "a product of the constant oscillation between analysis in the present of the past and conjecture into the future" [52, p.175]. In other words, "[h]indsight makes us map the present onto the past." [49, p.112]. By this, it is meant that the past can only be recalled with the knowledge of the present. "Seeing the past through the present, as we necessarily do, makes it impossible for us to describe it as it 'really was'" [48, p.648]. As such, it is impossible to recall the past 'objectively', because as an event transpires, the knowledge of the event occurred will inevitably add to our knowledge, and thus influence our perception of the event, as we regard it retrospectively:

> *"In hindsight, the meaning and status of events and actions become re-configured in the light of present experience or newly acquired data. The past itself does not change when new things happen, but our judgments of the meaning and significance of past events may change. [..] We see our experiences of the past in relation to what has happened since, as (re)understood from the present."* [48, p.646]

As the potential future gets actualized - as it becomes the present - it is added to our knowledge as an occurrence that has transpired; it becomes a past memory. Thus, as the event transcends from future, through present and into past, it alters our knowledge-base, and thus our recollection of that memory is influenced by the memory itself, through its transformation from a "memory of the future" to a memory of the past. Thus, "[t]he separation between past and future is not absolute but dynamic because the future becomes the past" [76, p.104]. In turn, as a 'memory of the past', the transpired event now informs our foresight through our use of hindsight. By this reasoning, we argue that the phenomenons of hindsight and foresight are very closely related to the concept of the hermeneutic circle, as there is a feedback loop evident between foresight, hindsight and experience, correlating to the basis of the hermaneutic circle in which the whole can only be understood in parts, as a part can only be understood as a whole[53].

> *"The hermeneutic circle is actually a spiral unfolding in time and allowing ever greater significance to emerge from what was already known, in the light of later acquisitions"* [49, p.113].

This very much aligns with our own working understanding of hindsight and foresight as a cognitive circular motion that loops eternally.

Hindsight and foresight are thus argued to be one of the origins of consciousness and as such human cognition. It is an ever changing circle in which the past is used in the present to imagine the future, only for this future to become the past and then get added to a cognitive library of experiences which shapes us as humans.

4.1.1 Biases of hindsight and foresight

As we interpret the past, it has been established that we are subject to multiple biases [29, 52, 39, 49, 48, 20]. With hindsight we look backwards in time [48]. However, when we look backwards in time, our retrospective recollection of memories of the past are based on our present knowledge, rather than the knowledge available when the event of the memory occurred. From a more philosophical viewpoint, this paradox can be regarded as the following:

> *"[T]he present image of something absent, or transpired, is the recollection; however, the transpired or absent thing is related to something that once existed"* [52, p.170].

As such, "[a]ny interpretation of history is bound inextricably with the memory of the interpreter" [52, p.170]. Although the latter is related to the work of historians describing historical events, we argue, that this is also apparent in any interpretation of the past, hence the past experiences of ourselves. For foresight, it has similarly been argued that "thinking about the past can distort our ability to understand the future." [52, p.163]. This coincides with the previous considerations of this paper, that foresight is affected by hindsight. As such, biases both occur when considering the past as well as the future. These biases can be seen as a result of the dynamic relationship between hindsight, foresight and experiences in the present, and are thus important to consider whenever working with experiences and memories. The following paragraphs, therefore seeks to elaborate on these biases.

4.1.1.1 Hindsight Bias

What can be considered one of the most well-established biases of hindsight is the "knew-it-all-along"-effect or the *Hindsight bias*. It is the result of the over-confidence that people gain once the outcome of an event becomes known to them. Hindsight bias is a concept that has gained traction and importance in several fields, from psychotherapy cases across politics and medical diagnosis to historical judgments [52]. At its core the hindsight bias is about wrongful predictions [52][20][7]. One of the early suggestions of the hindsight bias (although not named as such), was described by Baruch Fischhoff, as he stated that "postdictive likelihood estimates are exaggerated through a largely unconscious process evoked by receipt of outcome knowledge" [29, p.293]. The term "hindsight bias" was later coined by Arkes et. al. and described as:

> *"Those who consider the likelihood of an event after it has occurred exaggerate their likelihood of having been able to predict that event in advance."* [7, p.305]

As described, the phenomenon seems to stem from over-confidence [52][7]. We regard this bias as related to the previously described problem of recalling the past "as it was" since our knowledge-base has changed, as soon as the event has occurred.

> *"This adaptation of the knowledge base to the feedback then leads to hindsight bias if individuals are unable to directly retrieve their initial judgment, but try to reconstruct it by repeating the original judgment process, this time, however, on the basis of the updated knowledge base."* [39, p.136]

Being unaware of the active effects of the hindsight bias (as people mostly are), has been argued to potentially result in inaccurate predictions, and thus in inaccurate foresight [52].

4.1.1.1.1 Creeping Determinism While describing the functions of the hindsight bias, Baruch Fischhoff, coined the concept of *creeping determinism*, as he quoted the historian Georges Florovsky:

> *"The tendency toward determinism is somehow implied in the method of retrospection itself. [..] So that we get the impression that it really could not have happened otherwise."* [30, p.369]

This concept was initially fostered as a critique of the work of historians, or at least an attempt to create awareness of the inevitability of the order of events, that historians can have a tendency to describe. Fischhoff however, turned the notion into a general bias for people doing retrospection. Whether on their own lives or on others. Additionally, Fischhoff validated the existence of the *creeping determinism*, and like the hindsight bias, Fischhoff argued that "unperceived creeping determinism can seriously impair our ability to judge the past or learn from it" [29, p.298].

4.1.1.2 Foresight Bias

Expanding on the ideas of Fischhoff and Arkes et. al. (among others), MacKay and McKiernan have proposed the notion of *foresight bias*, as being a conjuncture of the hindsight bias and creeping determinism [52]. It is argued to occur when "[..] we take for granted perceptions and conceptions of what we think 'we know we know' about the past" [52, p.165]. I.e. when we are unaware of the varying influences occurring on our perception of the past, hence confining the possible potential futures we are able to imagine. As such it argues that the foresight bias, results in an over-simplified view of the future [52]. Whereas the previous biases were related to the retrospective perception of the past, the foresight bias directly connects the previous biases to the production of our 'memories of the future'. Hence, as we have previously argued, the foresight bias consider foresight to be influenced and informed by hindsight (also see section 4.1).

4.2 Cognition and Memory

In the previous section, we showed the dynamic relationship between foresight and hindsight, and how both are cognitive functions that are intrinsically linked to memory. Thus, the following section deals with cognition and memory, as we seek to clarify a link between neurological theories on memory with the concepts of foresight and hindsight, as seen in the previous sub chapter.

> "*[..] the cognitive processes that people engage in when generating explanations for the past and strategies for the future are interwoven*" [**p. 174**, 52].

Based on earlier work by Nielsen in 1958 [58][79], Endel Tulving proposed one of the most influential theories on the segmentation of memory. Together with Lars Nyberg it was termed *the multiple systems approach*. Albeit not all concur with this division of memory, it

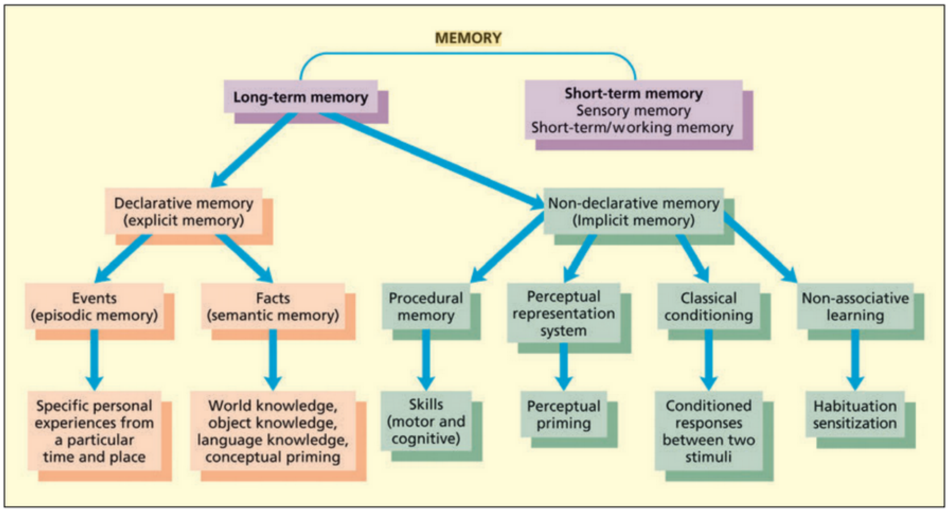

Figure 1: *Conceptualization of the various forms of memory as modelled by Jamie Ward [89, p.204]*

is a generally acknowledged conceptualization, that has continually evolved from its initial hypothesis in 1972 by Tulving[89][25][80]. Though these systems are believed to be independent (each serving specific functions), Tulving describes how "several systems usually interact in the performance of tasks"[80, p.67]. At the apex of this memory "hierarchy", the concept divides memory into *short-term memory* and *long-term memory*. Short-term memory has limited capacity and is defined as "memory for information currently held 'in mind'"[89, p.196], while long-term memory is defined as "information that is stored; it need not be presently accessed or even consciously accessible."[89, p.196]. As such long-term memory contain the memories of "things that happened several hours, days, or years ago"[89, p.196], even if that memory is not retrieved consciously in the present moment. Long-term memory can then be further subdivided into *declarative memory (explicit memory* and *non-declarative memory (implicit memory*[89].

Non-declarative memory, is considered as memories, or parts of the cognitive functions, that are not consciously accessible, like skills such as riding a bike, and cognitive systems for perception, like perceiving sounds, words, objects etc. Though not consciously accessed, they are still considered memory systems, as they store "knowledge of the perceptual world and are capable of learning"[89, p. 203].

By using declarative memory, on the other hand, the human mind has the capacity to operate with "meaningful sequences of events which are located in an anticipated future" [44]. In other words, the mind is able to produce memories of - or imagine if you will - events that have not yet transpired [52][44]. Thus, based on past knowledge and experience, we can infer and reason about a future potential situation, for which we have no direct memory; a situation that we have yet to experience [89, 44]. This sub-domain of long-term memory consists of *episodic memory* and *semantic memory*. *Semantic memory* can coarsely be described as "conceptually based knowledge about the world"[89, p.203]. I.e. the semantic memory ”concerns objects and their relations in the world at large”[80, p.67]. It is not linked to any personal nor unique episodes, rather it is learned knowledge, hence the semantic origin of the memory types name[25]. *Episodic memory* is regarded by Tulving as ”a unique extension of semantic memory, rather than a separate, parallel system”[80, p.67]. This form of memory, though, has the unique aspect of having an individualistic dimension, as this memory type is tied to personally experienced episodes[89, 80, 25, 79]. The common denominator for the two declarative forms of memory, is that they both work by storing information for later (conscious) retrieval.

By this reasoning, as the concepts of hindsight and foresight considers memories of past experiences, as well as ”memories of the future”[52, 44] respectively (i.e. ”information that is stored”), we regard hindsight and foresight, as seemingly highly dependent (and connected) to the interplay of semantic and episodic memory. Thus the following paragraphs, contain a closer examination of these two concepts.

4.2.1 Semantic memory

Semantic memory ”enables individuals to represent and mentally operate on situations, objects, and relations in the world that are not present to the senses”[80, p.67]. With the semantic memory system, we are able to infer about the possible outcome of an action, even if that specific action cannot be tied to a specific place or time at which we learned it. In other words, the semantic memory enables the use of foresight, as ”[t]he owner of a semantic memory system can think about things that are not here now”[80, p.67].

The term itself is several decades old, with Quillian et. al.[63] researching this memory type back in the 1960’s, with a focus on sentence understanding[63][19]. As previously mentioned, even before the 1960’s Nielsen[58] described a separate memory system that contains ”memories of intellectually acquired knowledge not experienced but learned by study and not personal”[58, p.25].

It is generally considered that semantic memory develops before episodic memory[89][80], as children learn how to navigate and exist in the world, before they are able to consciously link their knowledge to an event specific in time and place. I.e. ”[c]hildren are capable of learning facts of the world before they remember their own past experiences”[80, p.68]. As such, most semantic knowledge is also regarded as being learned in the first few years of a person’s life. Meanwhile, this does not necessarily mean that semantic knowledge does not get acquired later in life as well. On the contrary, *consolidation theory*[89] suggests that episodic memories might turn into semantic knowledge over time[76], since ”the older the event, the more consolidated it is”[89, p.211]:

> *”Older memories become more semantic-like and less episodic with the passing of time, because they get rehearsed more often. They become more like stories than memories”*[89, p.211].

Thus, the consolidation theory implies, like Tulving[80], a very close relationship between semantic memory and episodic memory, with the two working in parallel rather than individually.

Following this, *Binder et. al.* defined what can be considered a more modern approach to the distinction between semantic and episodic memory and this working relationship between these two types of long term memories:

> *"The content of semantic memory is abstracted from actual experience and is therefore said to be conceptual, that is, generalized and without reference to any specific experience. Memory for specific experiences is called episodic memory, although the content of episodic memory depends heavily on retrieval of conceptual knowledge."*[14, p.527]

The relationship is deepened as it also goes the opposite direction, as semantic knowledge must be gained from somewhere, which would also, in some cases, include from episodes which later moves to semantic memory[25]. Following the consolidation theories, this happens through rehearsal, until the original time based context fades into the background, and the knowledge, now freed, becomes more broad, as seen in amnesiac patients who have impaired episodic memory, but functional semantic memory[73][89]. In regards to hindsight and foresight, we therefore find it reasonable to argue, that semantic memory can be considered a prime requisite for foresight. Though possibly informed by past experiences, and thus not working independently from episodic memory, humans are commonly able to assess the outcome of a potential action or respond properly to a given situation, even without relating it to a memory of a similar situation specific in time and place.

4.2.2 Episodic memory

Episodic memory, is a "neurocognitive memory system that enables people to remember past happenings" [80, p.69]. Hence, Endel Tulving originally defined episodic memory as such:

> *"Episodic memory receives and stores information about temporally dated episodes or events, and temporal-spatial relations among these events"* [25]

However, episodic memory is not believed to be exclusively restricted to past events anymore, as Tulving has later described how "[t]he owner of an episodic memory system is not only capable of remembering the temporal organization of otherwise unrelated events, but is also capable of mental time travel: Such a person can transport at will into the personal past, as well as into the future, a feat not possible for other kinds of memory." [80, p.67]. As such, the distinction between episodic and semantic knowledge lies in the temporal-spatial aspect, as Tulving described how episodic memory is the only way to disrupt the linear flow of time [79], while semantic knowledge is not bound temporal-spatial in the same manner. Episodic memory is, according to Tulving, seemingly uniquely attributed to humans, as animals do not seem to have this mental ability to look backwards in time (or at least, to the best of our knowledge, it has not been possible to verify this ability in animals), which might very well be the root of the human ability to self-reflect. Tulving points to three factors, which together creates the episodic memory[79]:

- Sense of subjective time

- Autonoetic awareness
- Self

These three factors are all found exclusively within humans, and they are considered the very base of mental evolution, from child to adult [76]. The *sense of subjective time* condition, is fairly self-explanatory, as it simply argues that in order to have episodic memory, one must be able to distinguish between past, present and future. The condition of *autonoetic awareness* is specifically defined by Tulving to be "the kind of conscious awareness that characterizes remembering one's past"[80, p.68]. Finally, the *Self* is regarded as not only consciousness about the self as different from the rest of the world in the present, but as having a self in subjective time. Summarizing these three conditions for episodic memory, one must be able to consciously retrieve (in the present) an individual and personal memory of the past, or imagine a personal potential future.

Episodic memory has another distinction which makes it unique, as Tulving cautiously states, that there are barely any tasks (if any are to be found at all), that one can perform to test the episodic memory, due to its subjective and changing nature[79]. One can ask themselves, how would it even be possible to test whether or not a subject properly remembers a subjective episode, which can by its very definition only be verified by the very same subject? As described with foresight and hindsight, it can be argued, that all memories are affected by the knowledge collected and available in the present, effectively making it impossible to remember any event "as it was" (see section 4.1 and 4.1.1). It has even been argued, that "[e]ach time an old event is remembered, this creates a new memory for that event"[89, p.211]. If we acknowledge, that any retrieval, and thus interpretation, of a memory (hindsight) is always affected by the knowledge in the present, it does seem plausible, that the memory is stored as a new memory, following the new interpretation of the memory. However, we do not see this subjective nature of episodic memory as an issue, as the current study, does not seek to examine the accuracy of episodic memory, but instead seeks to identify any potential markers, which could indicate the use of episodic memory (through hindsight/foresight). Thus, the subjective nature of episodic memory is inconsequential to this study.

The fact that episodic memory, and semantic memory, is difficult to pin down and analyse on its own in a laboratory setting, have been the source of some critique since their conception. One of the focuses being the lack of neurophysiological proof for these memory types, as without it, the theoretical background and analysis would be without merit, according to Ratclif et. al.[69]. This critique, one of the major ones as it was directly taken up with Tulvin, and later cited by Tulving himself in his 2002 review of the memory types, is not without merit. However, in recent years, research on biological proof and biometric markers for episodic memory has escalated. With far more advanced brain scanning tools becoming available from the mid 90's, this memory type has advanced from a solely theoretical field, to a practical one as well[11][47][88]. The use of psycho-physiological measurements in this regard, will be further expanded upon in the method section (*see section 5*).

If we acknowledge the premise, that episodic memory affords a person the ability to freely access the personal past[80], as well as envision a possible future scenario, the reliance on the temporal dimension is apparent. As previously mentioned, this time-distorting cornerstone, is also present in the theories of mental time travel [54][80].

> *"The act of remembering a personally experienced event, that is, consciously recollecting it, is characterized by a distinctive, unique awareness of reexperiencing here and now something that happened before, at another time and in another place"*[80, p.68].

By this, we argue that hindsight/foresight are closely related to (and quite possibly working by) the episodic memory. By re-experiencing something from the past, in the present (hindsight), not only makes us "map the present unto the past"[49, p.112](see section 4.1), but also informs our expectations as to what will happen in the future (foresight).

> *"[The past is] altered by the present as much as the present is directed by the past"*[24, p.37]

The inter workings of episodic memory and semantic memory, likewise seems clear, if we consider foresight. As such it has been stated that "general knowledge or semantic memory plays a crucial role in constructing and thinking about future personal events."[54, p.214]. While episodic memory might inform foresight, "humans do not merely predict that what happened in the past will reoccur" [76, p.100], but are also able to imagine something not yet experienced. Hence, we can infer, that semantic memory also greatly aids in foresight, as it allows an individual to apply all the general knowledge gathered in their lifetime[25], to imagine a novel situation.

4.2.2.1 Adaptive episodic memory

The previously mentioned paradox of remembering past events in light of the knowledge of the present, and then using that reevaluated knowledge to guide future decisions, have also been dubbed *adaptive episodic memory*, by Thomas Suddendorf[76]. It is argued, that there is a connection between motivation and which events are memorized or stored in memory, which has been suggested to be a function evolving as a consequence of limited capacity in our brains[61][22]. Instead of storing every event we encounter in our memory, the idea of adaptive episodic memory, is that the human mind has a system to utilize each memory in a multitude of novel situations. This follows the idea described in the previous section, that we are able to think about future scenarios that we are yet to experience. However, where Tulving focused on the semantic memory as a key component in constructing mental images of future scenarios (as he argues that episodic memories can turn into semantic memory over time), Suddendorf instead argues, that this cognitive function is due to a flexibility or adaptivity of the episodic memory. By this reasoning, it could be argued that the mind conjures relations between various part of different episodic memories, and are therefore able to recombine these elements in order to imagine, anticipate and react to a novel situation. The concept of adaptive episodic memory, hereby expands upon the initially defined properties of episodic memory, by applying an adaptive trait to this form of memory. By *adaptive*, Suddenforf explains that "[i]n the light of new information, we may then revaluate past events and what they can teach us"[76, p.104]. Furthermore, the adaptive feature of episodic memory, along with the elementary functionality of episodic memory, grants us "access to detailed episodes [and] makes it possible to connect events and reassess them as a whole"[76, p.104]. As we have argued for hindsight/foresight, Suddendorf thus argues, that there is a feedback-loop between past memories, present experiences and future predictions, or as Suddendorf describes a "cycle".

> *"People reason about the match or mismatch between memory of what was expected and memory of what actually occurred and this analysis informs their next anticipations. This cycle of prediction, comparisons between memories, updating of explanations, and forming new predictions, is extremely powerful"* [76, p.104].

In short, adaptive episodic memory means we as humans use powerful memories rather than everything we absorb, so the most salient, or sometimes recent, event takes over, even if it might actually be wrong. Because of this, the most recent or most extreme version of a memory, such as a train ride, decides how we use foresight to imagine the next train ride.

4.2.2.2 Episodic foresight

In the previous sections, we have demonstrated how it can be argued, that episodic memory works both backwards in time, as well as forward in time. This functionality of the mind, has also been coined as *mental time travel*[80][54][76][38]. A variant of this feature, however, has also been described as *episodic foresight*[76][54] or *episodic future thinking*[8]. With episodic foresight, the focal point is not on the past experiences themselves, but on how these past experiences inform our expectations about future scenarios. Thus, episodic foresight is mainly utilized in dealing with potential future problems and obstacles[51][9]. In the theories of mental time travel, it has likewise been argued that "mental time travel involves, [..] a 'recombinable system', in that it allows us to put together parts in different ways to generate novel situations and scenarios" [38, p.539]. In simple terms, episodic foresight, is the ability to mentally travel backwards in time to specific episodes, in order to use the interpretation of these, to assess a future scenario, and even imagine scenarious not yet present to the senses. Hence, it has been argued to have a practical appliance in human evolution, as it enables us to reflect and grow. Thomas Suddendorf even argues that episodic memory exists for the use of episodic foresight; that episodic memory in general is a memory that works forward, in which the backward reaching dimension is merely a side effect [76]. He cites Endel Tulvings research into amnesiac patients without any memory of the past, who where unable to imagine a future. I.e. without a past there was no future [76]. Albeit, it has been shown that in some amnesic patients, the patients were able to imagine public scenarios of the future, but not personal ones.

As such, episodic foresight (or episodic future thinking), does not disregard semantic memory completely, as the general knowledge found in semantic memory is then regarded as being utilized in *semantic future thinking*[54][8]. This also works by using long-term memory to make predictions about the future, although the main difference is *certainty* and *self*. While episodic foresight is about predicting an uncertain future, and projecting one

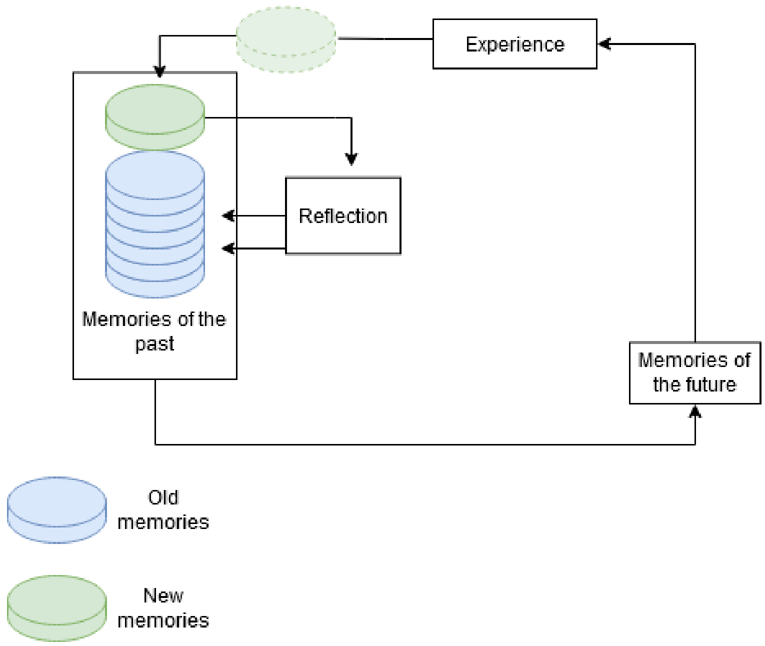

Figure 2: *Conceptualization of the interplay between experience and memories*

self into this future scenario, semantic future thinking is about what can be considered a generalized *known future*[54][8]. The term can be exemplified with physical laws, such as gravity, where we have a fairly grounded and probable idea of how it will behave on a certain object.

By regarding the notion of episodic future thinking or episodic foresight, we demonstrate some of the various views on episodic memory and its features. However, whether we acknowledge the theory of mental time travel, episodic foresight or episodic- and semantic future thinking, we find it evident, that a common denominator for these views is a dynamic relationship between experiences of past, present and future. As with hindsight/foresight, we argue that the presented conceptualizations of memory storage and retrieval, display that experiences in the present, inform our interpretation of the past, which in turn affects our anticipations of the future (see fig. 2).

4.3 Narrative Theory

As the previous sections have argued, hindsight and foresight is intimately connected to memories; memories of the past and memories of the future. And all of these can be said to be influenced by our experiences in the present. Similarly, narratives are experienced in the present, while new information about both narrative past, present and future can be afforded the reader through various techniques.

4.3.1 Time, Memory and Narrative

In order to relate, and potentially unify, the previously described theories of memory and foresight/hindsight to narratives, we therefore find it pertinent to initially examine the common denominator of all three: Time.

The phenomenon of Time

Time has been discussed by several different fields, such as philosophy, psychology, physics and narratology an interesting concept to consider. This study seeks to enlighten our understanding of memory and perception, which are both intrinsically linked to time (e.g. by past, present and future - see section 4.1 and 4.2). When we consider time in everyday life, we usually regard it as a measurement and not a phenomenon. This distinction can crudely be characterized as the difference between the considerations of time by physics and philosophy respectively. As this project primarily works with the human *perception* of time, e.g. how our minds utilize time in the ordering of experiences, the current section will focus more on time as a phenomenon even though we might also use it as a measurement along the way.

The current section will primarily focus on the works of Aristotle, St. Augustine and Paul Ricoeur, although theories of others will be integrated as well, whenever deemed relevant.

The tripartition of the concept of time into past, present and future, is a well established notion, originally formulated by St. Augustine between 397-400AD[44]. Although the past-present-future paradigm dates back to the 4th century, the philosophy of the concept of time has been studied much earlier, going back to the times of Plato and Aristotle. Aristotle continued the ideas of Plato, but greatly expanded upon the subject of time. More specifically Aristotle defined *time* as being the "number of change with respect to the before and after" [21, p.1]. In other words, in order to have time, you must have two different states, the *before* and the *after*. By Aristotle's definition, in order to have these two different states, there must be a change (a movement); the before must have changed in some way, must be different from the after. Following this, Paul Ricoeur pondered this notion of movement in his 3rd volume of 'Time and Narrative':

> *"If there is no perception of time without the perception of movement, there is no possible existence of time itself without that of movement"* [68, p.15].

Ricoeur here argues for time's dependency on movement. This follows Aristotle's own reflection, as he stated that "[i]t is evident, then, that time is neither movement nor independent of movement"[13, Physics IV.219a2].

With the concepts of the before and the after, Aristotle provides a structure of time that we find useful. A way to chart time as a continuous line with before and afters. Much like the later work of St. Augustine, this was a way of regarding time as a line with *befores* and *afters*, which shows similarities to the theories presented on hindsight and foresight (see section 4.1).

One paradox we find in this interpretation of the work of Aristotle, however, is that whenever there is a *before*, then there is an *after*, but that same after, is actually the before of another after (see figure 3. As such, how does one define when something is a before or an after? How do we define an origin from which to 'measure'? Or more along the work of this study: how does the mind organize the experiences of the present as memories of the past and memories of the future?

Aristotle described the parameters of the *before* as being "nearer some beginning"[70]. As Aristotle only mentions *some* beginning, or the "first mover"[21], we find that he leaves it open to determine what beginning, i.e. origin, to relate the before and after to.

It could then be argued that the before and after is being nearer to or further from any decided comparative point in time, chosen as "some beginning". E.g. by thinking about last years holiday, we can decide if that was a before or an after, by examining it in relation to either this years holiday, or a holiday several year earlier. Nonetheless, this interpretation does not take into account, that at any point in time, the before and after might be of equal distance to that comparative point. Hence, how then, might the mind identify what is before and what is after if none is further away from the comparative point?

Some have argued, that Aristotle defined *the present* as this origin, to which we can relate the *befores* and *afters*. "[T]o be before or after in time is to be nearer to or further from the present" [21, p.3]. However, as it has also been noted, by deploying *the present* as the origin, will mean that "[i]n the future, what is before is nearer to the present, but in the past what is before is further from the present"[21, p.3]. By this, we can also say that in the future what is after is further from the present, but in the past what is after is nearer to the present. Thus, by this understanding, the past, present and future, all contains both *befores* and *afters*, and from any point in time, you can discuss things that were before that point and things that were/are after (see figure 3).

Albeit logical, this definition introduces a multitude of dimensions to the befores and after, as the befores of the future transcends across the present and into the past, and the afters of the past likewise transcends the present into the future. Coope has similarly described how "[w]e cannot mark out temporal order by measuring the distance of different events from the present, since there would be no one present" [21, p.4]. This follows along the lines of Paul Ricoeur, who similarly has argued that one of the differences between Aristotle and Augustine, is that Aristotle does not refer to a single *present*, but instead discusses the term *instant*. Ricoeur argues, from the Aristotelian view of time as related to movement, that "[t]o be thinkable, the Aristotelian 'instant' only requires that the mind make a break in the

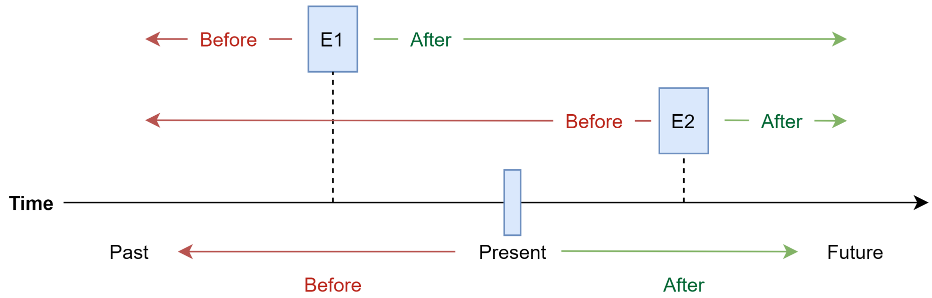

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Figure 3: *Befores and Afters on a continous line symbolizing Time*

continuity of movement, insofar as the latter is countable. This break can be made anywhere. Any instant at all is equally worthy of being the present" [68, p.19]. As Ricoeur stated, "[t]he present, for him [Aristotle], is only an instant that is situated" [68, p.21]. As such, like Coope, we argue that we need at least two references to determine the befores and afters. However, unlike Coope we envision that *some* beginning is actually *the* beginning. Although this might seem grandiose (and can be argued to be flawed, as Aristotle has argued that 'time' has no beginning[13, Physics VIII.1.251a8-251b10]), it follows along the ideas of Augustine, that time started when the world was created[90]. It must be emphasized, however, that no effort is done in the current study to try to define this hypothetical beginning, and we regard it solely as a metaphysical instance which we can determine as an origin for subsequent evaluation of *instants* in time.

From this understanding, the present is simply an instant in time, just as any event in the past and the future is an instant in time. The present is then merely a theoretical construct to separate what we call 'past' and 'future', from the point in time in which our corporeal form is located. Hence, any point in time will have a 'past' and a 'future' or a before and a after.

From the concept of the *befores* and *afters*, Aristotle introduces the idea that time is constantly moving (i.e. change is constantly occurring), from the past (as something we can understand), into the present (which is already gone) and into the future (which is yet to be experienced). Friedrich Nietzsche views time in a similar manner, albeit as seen from the opposite direction. He describes how the future is not here yet, and only potentially will be, and when it does arrive in the present, it slides directly into the past and is no longer neither future nor present [35]. Similarly, Aristotle described how "[i]n time all things come into being and pass away" [13, Physics IV.222b16-20].

> *"For time is by its nature the cause [..] of decay, since it is the number of change, and change removes what is"* [13, Physics IV.221b1-2].

Combining the notion from Nietzsche, that the future is only potential, with the ideas of Aristotle, one might even go as far as to argue, that there are no befores in the future, only afters. As all events in the future come after *the present*, and are only potential (since we can never be sure that they will be actualized), how might we discuss a potential event in

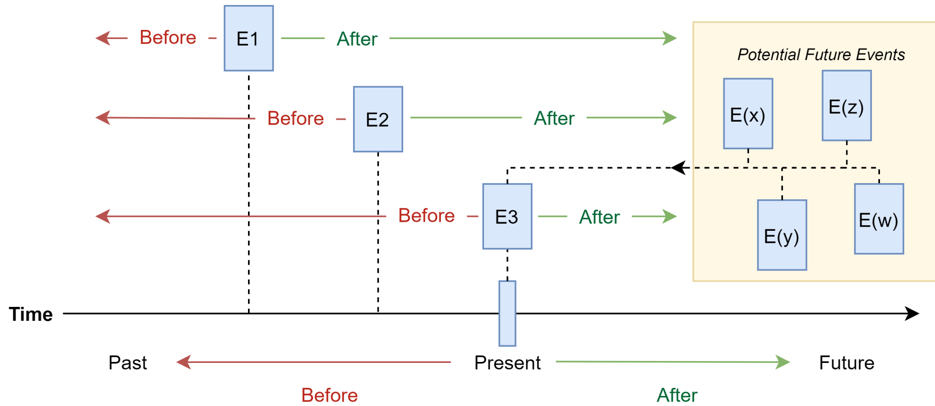

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Figure 4: *Befores and Afters with relation to the present*

the future being a *before* of another event, when both events are naught but potential? If we imagine a future event, like a dinner party, we can only *imagine* how it might come to be, but never *know* how it actually will be. As such, we can not with certainty describe what comes *before* that event, only that it comes after *now* - the present - this instant. I.e. the order of future events can never be determined in absolute. Thus, the order can only be determined as it transcends from the potentiality of the future, through the present and becomes part of the past. As such, it can be argued, that only the past holds both befores and afters, and the future only holds afters. This view would then suggest, that all events are viewed in relation to the present (see fig. 4). Ricoeur also describes this possible anchoring in the present, as he argues that Aristotle's focus on movement and the instant, "does introduce a certain notion of the present related to the becoming that constitutes the actualization of potentiality"[68, p.20].

Nonetheless, logically the mind is able to determine that shopping for groceries comes before the making of the dinner, and we therefore argue, that as we can imagine the events in the future, we are also able to structure the *potential order* of these events, and in our minds we will thus be able to define befores and afters in both past, present and future - Also known in narratology as causal links.

As described in the section on hindsight and foresight (see section 4.1), we see a very similar dynamic between hindsight and foresight, and this dynamic between future, present and past, and we believe that the view of Nietzsche, with the future flowing towards the present as time moves forward, is a very fitting metaphor for the "workings" of time, as it insinuates that time does not stand still, even if we do. It is also a metaphor which has been used by others [52]. With this definition of time, the present is a very elusive instant in time (as previously described), but for modelling the workings of hindsight and foresight, as well as explaining an instant in time on the narrative trajectory, it still serves a crucial purpose in trying to obtain a snapshot of time.

Narrative Time

With this conceptualization of time and the human perception of it, we find it prudent to investigate the notion of time in the context of narratives. Especially if we consider the idea of *narrative intelligence*[15], that humans perceive the world through narratives. I.e. humans think narratively, as our minds automatically construct a narrative around the information we are presented with, to put it into context and try to make the information coherent [3]. Paul Ricoeur has likewise argued for this connection between life and narratives[37], as he states how human "life can be understood only through the stories that we tell about it" [66, p.31]. Fitting for this study, Paul Ricoeur has also specifically looked at the temporality of narratives, as he sought to construct the correlation between time and narrative[67, 68, 37]:

> *"[T]ime becomes human to the extent that it is articulated through a narrative mode, and narrative attains its full meaning when it becomes a condition of temporal existence"*[67, p.52]

Ricoeur's ideas is formed from his approach to a paradox he has described as emerging from the remarks of a commentator: "stories are recounted and not lived; life is lived and not recounted"[66, p.20]. Considering this paradox, Ricoeur forms the thesis above, and simultaneously ponders the aspect of time in narratives. Ricoeur argues that there are two different forms of time in every narrative: a discrete successive series of incidents and the configuration of these incidents:

> *"We could say that there are two sorts of time in every story told: on the one hand, a discrete succession that is open and theoretically indefinite, a series of incidents (for we can always pose the question: and then? and then?); on the other hand, the story told presents another temporal aspect characterized by the integration, culmination and closure owing to which the story receives a particular configuration"* [66, p.22].

We might crudely compare this to the familiar notions of *story* and *discourse*. This would follow along Ricoeus statement that by the above "composing a story is, from the temporal point of view, drawing a configuration out of a succession[66, p.22]. However, these notions does not necessarily integrate the role of the reader (or user), as Ricoeur does. He proposed that "emplotment is the common work of the text and the reader"[66, p.27]. He thus integrates the reader as a partner in the narrative, and hence in the narrative understanding[66]. From this he focused on three aspects of narratives: *Configuration*, *Reading*, and *Refiguration*[67].

Configuration, as indicated above, is the narrative structure of the incidents. Not to be confused with the narrative discourse, *configuration* "transforms the succession of events into one meaningful whole"[67, p.67]. Ricoeur further describes that the "configurational act consists of 'grasping together' the detailed actions or [..] the story's incidents. It draws from this manifold of events the unity of one temporal whole."[67, p.66].

Reading is seen as the mediating factor between the configuration and refiguration act, as "it is the act of reading that accompanies the narrative's configuration and actualizes its capacity to be followed"[67, p.76]. Ricoeur further describes that "[f]ollowing a narrative is reactualizing the configuring act which gives it its form"[66, p.27].

Refiguration is the point where the "world of the text" collides with the "world of the reader". It is "the refiguration of temporal experience"[68, p.4], or in other words, "the refiguration of time by narrative[68, p.4]. By this, Ricoeur envisions how the horizon of the work and the horizon of the reader fuse, much like Gadamers hermeneutic "fusion of horizons" when understanding a text [66]. In other words, by the incidents described and configured in the narrative we reflect upon the events of our own life (and their meaning as imposed by cultural prefiguration) by refiguration, and "[a]s a result, the reader belongs at once to the work's horizon of experience in imagination and to that of his or her own real action"[66, p.26]. Based on this, Ricoeur proposes a form of answer to his initial paradox, as he argues that "stories are recounted but they are also *lived in the mode of the imaginary*[66, p.27].

Ricoeur thus connects narrative, time and life through these three acts, as he argues that "the process of composition, of configuration, is not completed in the text but in the reader and, under this condition, makes possible the reconfiguration of life by narrative"[66, p.26]. He hereby establishes how we might equate narratives with lived experience.

Our judgment of Time

If we acknowledge the thesis that narratives are "*lived in the mode of the imaginary*"[66, p.27], which suggests to follow from the thesis that "time becomes human to the extent that it is articulated through a narrative mode"[67, p.52], we find it logical to assume, that we employ similar cognitive functions for the perception of narrative events, as we do with the events of our own lives. Whether perceiving event in the world of the narrative or the world of the person that experiences said narrative, we argue, that both are conscious acts utilizing analogous recognitions of time.

By following the reasoning of Ricoeur, we are able to draw parallels between memory, imagination and narratives. Refiguration happening as a result of the reading (or more properly the edification) of a narrative, can then be compared to our previous description of hindsight, in which we determined that "[i]n hindsight, the meaning and status of events and actions become re-configured in the light of present experience or newly acquired data"[48, p.646]. We thus argue, that hindsight is evident both for events experienced in "lived time", as well as events experienced in "narrative time".

One thing still missing though, is how our mind actually structure these *instants*, as for us to discuss befores and afters of a specific instant. If we consider time as described by Aristotle, one might argue, that the mind structures the events based on relationship of change, i.e. through causal connections (B cannot have happened unless A was actualized). Similar notions have been suggested for our interpretation of narrative events[40][2]. Even if we are not necessarily able to pin-point the accurate date of an *instant* in our lives, we are often able to determine if it was before or after another *instant*, based on inference of causality. We might vividly recollect images of the day we got our driver's license, even if we do not remember the exact date. However, we most likely will be able to infer that it was *after* our 18th birthday (or whatever age is legal for driving in the country of our upbringing) and *before* our first road trip with some friends. This can also be argued to be because of semantic memory (*See section 4.2.1*), meaning that we are able to deduce these causal links. Similarly, in narratives we are often presented with information in a non-chronological order, and are able to order it by these causal connections. E.g. we might receive information about a medical bill, and then later information concerning an "incident", and then again later, obtain peripheral information about an accident in a mine. We are then usually able to determine or propose a relationship between these parts of information, and order them by causality (the accident comes before the medical treatment). This might be compared to the act of configuration as described by Ricoeur, which can be regarded as a function of the human mind, to order incidents into a structured whole. Furthermore, Ricoeur argues, that configuration is dependent on our *prefiguration*, which can be regarded as our "preunderstanding of the world of action, its meaningful structures, its symbolic resources, and its temporal character[67, p.54]. Hence, Ricoeur believes that our narrative understanding is influenced by our cultural heritage, as our expectations and ability to follow a narrative greatly depends on this *preunderstanding*. The importance of *prefiguration* and its connection to our understanding of *action* is further accentuated as Ricoeur argues, that "[t]o understand a story is to understand both the language of 'doing something' and the cultural tradition from which proceeds the typology of plots"[67, p.57]. He even goes as far as to claim that "literature would be incomprehensible if it did not give a configuration to what was already a figure in human action"[67, p.64]. Ricoeur makes these arguments, as he states how "the work of imagination does not come out of nowhere. It is tied in one way or another to the models handed down by tradition"[66, p.25].

Similar behaviour can be argued to be evident when thinking about the future. Even though we can never determine an absolute order of events, it is through causality (or the dynamic relationship between prefiguration, configuration and refiguration) that we are able to establish a plausible, albeit still potential, order of future events. As such, we again can find similarities between the dynamics of hindsight/foresight and the dynamics of prefiguration, configuration and refiguration. Configuration in the "present" makes us reflect upon the past through refiguration, which in turn informs and alters our prefiguration. Ricoeur likewise forms similarly principles, as he states that "following a story is a very complex operation, guided by our expectations concerning the outcome of the story, expectations that we readjust as the story moves along, until it coincides with the conclusion"[66, p.21-22]. In other words, it might be said that "everyday praxis orders the present of the future, the present of the past, and the present of the present in terms of one another"[67, p.60].

As we have now established a form of relationship (albeit a tentative one) between time, life and narratives, and how the mind might be said to structure the various instants *in time* for both life and narratives similarly, the following section will further explore the various "games fiction plays with time"[67, p.84]. Even if the reader can be said to *configure* the narrative through reading, it still stands, that this configuration happens in a form of collaboration with the author, through the composition of the narrative. As such, this composition will be our next point of inquiry.

4.3.2 Analepsis and Prolepsis

Some of the most common tools for manipulating narrative time, are through the use of *prolepsis* and *analepsis*, i.e. *flashforward* and *flasback*. Analepsis and prolepsis as tools, are used to control the temporal order of the story, and thus control the flow of information to the reader. As such, These terms are therefore often regarded from the perspective of compositional mechanics. However, for this study, such a view, might not sufficiently cover the cognitive functions, that these tools actually actuates. The following section will therefore explore how the manipulation of narrative time, through these tools might evoke or influence hindsight and foresight in narratives.

For this study, we employ Genette's terminology of analepsis and prolepsis[34]. By this, narratives can be regarded as constant manipulation, or tweaking if you will, of information in the user's memory. While experiencing a narrative, new information about the story is constantly presented to the user through the narrative discourse, and subsequently the user's perception of the events in the story is continuously updated as the user's memory conforms to the new information. Ergo, it can be said, that the user utilizes hindsight and foresight in their perception of the narrative, and as such, for a study concerning recognition of the cognitive workings of hindsight and foresight in narratives, prolepsis and analepsis are unavoidable elements from narratology that must be addressed.

4.3.2.1 Analepsis

In narratology, analepsis is regarded as one form of anachrony in narratives. In other words, it is a "discordance between the two temporal orders of story and narrative"[34, p.40]. Gérard Genette initially described *analepsis* as "any evocation after the fact of an event that took place earlier than the point in the story where we are at any given moment"[34, p.40].

A more popular term revolving around the notion of analepsis, is the narrative device of *flashback*. Flashback, as opposed to the original definition of analepsis, seems more simplified and uniform, as it can be described as "[g]oing backwards in time to cover an earlier episode"[40, p.14]. However, flashback can also be regarded as a more ambiguous term, because of its multitude of adaptations across different media [40, p.591], which might also attest to its more popular usage, compared to analepsis. In this sense, *flashback*, has for example been regarded to cover both momentary "jumps" in narrative time to describe backstories or small episodes happening before the current narrative *now*, as well as entire main stories told in retrospective. However, we find the latter to be a misinterpretation of the term, as the name itself *flash*-back suggests a rapid, temporary change of position in the story *back*wards. On the other hand, the fairly neutral description of analepsis, leaves room for different forms of analepsis, as it describes "any evocation [..] of an event that took place earlier". As such, analepsis both describes repositioning along the same time- and plotline as the current, as well as repositioning to a completely different plotline. It also permits varying durations of these repositionings.

As such, although *flashback* might be regarded as a more popular term, and is often used as a reference (like we do) when describing the functions of analepsis, we regard it (as others before us[]), as but a subcategory of analepsis in the sense, that we see it as a narrative device with a multitude of sub-tools to create a flashback in a narrative, and thus to achieve analepsis.

This study therefore might be able to draw upon narrative devices such as *flashbacks* for the design, but focuses on the initial definition by Genette, in relation to the workings of hindsight and/or foresight.

4.3.2.2 Prolepsis

Originally, prolepsis was described from a rhetorical point of view at the times of Aristotle[18]. In rhetorics, prolepsis (or procatalepsis) is used to describe the act of raising an objection towards ones own argument, only to immediately answer that same objection. It is thus used to strengthen ones position by "anticipation of and answering of an argument before it has been made"[78, p.144] by the audience or the counterpart. But, like analepsis, the term *prolepsis* gained traction within narratology, after it was defined by Genette.

Prolepsis can essentially be regarded as the opposite of analepsis. Thus, prolepsis "presents what will happen in the future with respect to 'now' in the story[16, p.156]. Originally, Genette defined prolepsis as "any narrative maneuver that consists of narrating or evoking in advance an event that will take place later"[34, p.40]. Genette does not here go into detail on the intentions behind *narrating* or *evoking* in this definition. Thus, Genette provided a foundation for the workings of prolepsis, but not an absolute definition. Accordingly, prolepsis has also been described as being "anticipation of a future episode that results in a non-chronological presentation of events; a flashforward. Prolepses reset the narrative clock by jumping to a new 'narrative now'"[40, p.468]. This description shows this somewhat ambiguous understanding of prolepsis, as it both entails an overarching definition (comparable with that of Genette) as well as more specific interpretations in the form of *flashforward* and the description of the resetting of "the narrative clock by jumping to a new 'narrative now'". As *flashforward* most often are regarded as such a *jump* in the narrative time, this definition seemingly has a higher focus on repositioning in narrative time through the narrative trajectory. As can be seen by this definition, the term *flashforward* and the term *prolepsis* can be seen interchangeably, although some regard flashforward as a subcategory of prolepsis, together with terms like *foreshadowing*[16]. As with analepsis, Rev. Andreas Hoeck tried to categorize prolepsis based on examples from the Bible[41]. Hoeck extracted a total of 6 categories of prolepsis:

- *Absolute*. A flashback to an earlier point outside the narrative.
- *Toponymical*. Callback to a locale (geographical location) mentioned earlier, to give cohesion to a narrative.

- *Supra-temporal.* A paradox, when something is mentioned both before and after.
- *Festal.* It revolves around Jewish festivities, using calendar events as time markers, mostly used in Bible.
- *Eschatological.* An eternal perspective, mostly used in Bible
- *Anamnestic.* This is about remembering the past. The characters in the gospels always remembers something said to them, because they keep forgetting it.
- *Transmutative.* When one item is reused in another way.
- *Synoptic.* References the synoptic gospels, with one quote that is lifted from an earlier gospel.

These categorizations might serve for analysing the structure of a narrative. However, as Genette describes prolepsis as being "any narrative maneuver", we find these subcategorizations of prolepsis to mainly be various narrative devices to obtain a similar outcome: providing the reader with information about events occurring *after* the current narrative *now*.

Following this, we interpret the overarching definition by Genette as entailing both maneuvers that switch the position of the reader to a new temporal position *after* the current *now* in the timeline of the story, as well as descriptions in the current *now* of events that will take place later in the timeline of the story; i.e. events that the are depicted as expected to take place. By this understanding, we see a closer connection between the workings of analepsis and workings of prolepsis, much like has been shown to be evident for memories of the past and memories of the future (see section 4.2).

4.3.2.3 Temporal Ordering and Cognition

After describing the functions of analepsis and prolepsis, we find it crucial to examine the temporal ordering of narratives that these concepts affect, and relate this to our understanding of hindsight and foresight.

As previously described, Genette encompassed both analepsis and prolepsis under the general term of *anachrony*, which he defined to include all forms of "discordance between the two temporal orders of story and narrative"[34, p.40]. Like Ricoeur, he thus acknowledges the presence of two modes of time in narratives. To unify these understandings, this study will employ the notions of *story* and *discourse*, which follows along (and might even be regarded as similar to) the Russian Formalists understanding of fabula and sjuzhet, and the French terms of histoire and discours, all of which together makes up the *narrative*[40][2]. The distinction of story and discourse, serves to separate the chronological sequence of narrative events (story), from the sequence in which they are presented to the "consumer" of the narrative. As such, the discourse is the bottleneck through which information on the story is filtered, and thus controlled, as it is presented to the "reader". However, describing story as *chronological* might in itself be faulty, as it suggests a perception of the *narrative* *instants* in relation to a measurement of time. Often though, events in fictional narratives are not specifically presented in "time", and "usually signifies an unspecified past"[40, p. 611]. Hence, the narrative events are often presented in relative relationships between each other, and, in regards to written narratives at least, it has been argued that "[t]he cognitive order of the reading process is therefore closer to the experience of time than to the notion of clock time extending uniformly from past into future"[40, p.610].

> *"Whereas empirical time is conceived of as a continuum with each point of reference yielding a view both back into the past and forward into the future, what complicates matters in fictional narrative is the determination of a focal point of reference"*[40, p.611].

Following this notion, the initial thing we notice in Genette's description of *analepsis* is the last part where he describes what we might call the *narrative now* as "the point in the story where we are"[34, p.40]. As such, it is not difficult to envision the story as a line or sequence of chronologically arranged narrative events (or "instants" to use the term from Aristotle regarding time). However, if we complete the sentence to include "the point in the story where we are *at any given moment*"[34, p.40], we find similarities to our previous understanding of time (see section 4.3.1), in which the point of reference can be any *instant* that we evoke either from our *memories of the past* or our *memories of the future*. Genette's description further describes that analepsis entails presenting events taking place *earlier* than the current *narrative now*. As the "point in the story where we are at any given moment" can both be in the middle of the narrative, but can also be the very beginning of the "reading" of the narrative, an earlier event will have to be interpreted as happening *before* the beginning of our consummation of the narrative. That humans are able to do this, supports our understanding of time as being deduced from perceived relations between *instants*. If the discourse does not specifically indicate a duration (as measured in time by units - seconds, minutes etc.), how are we able to deduce a case of analepsis, if not by causal connections or relations?

> "B *is thus temporally subordinate to* A*: it is defined as retrospective* in relation *to* A*"*[34, p. 39].

Following this, we suggest, that as we are able to be repositioned on the "timeline" of the story, we are only able to do so, because our minds are able to "follow" the story *despite* these repositionings. This serves as an argument for our mind's focus and ability to infer causal links and relationships between "instants". As Ricoeur stated, "[t]o understand the story is to understand how and why the successive episodes led to this conclusion, which, far from being foreseeable, must finally be acceptable, as congruent with the episodes brought together by the story"[67, p.67]. In other words one might say, that to understand the story is to understand the "instants" of the story, and how they are positioned as befores and the afters in relation to one another (even without temporal information in measurable units about the instants). As such, anachronies such as analepsis and prolepsis, are part of the composition of the story (the narrative discourse) from which "[w]e must follow, accompany configuration and actualize its capacity for being followed if the work is to have, even within the boundaries that are its own, a configuration"[66, p.27].

Considering hindsight and foresight in this regard, there seems to be a correlation. For hindsight and analepsis, both involve events that happened *earlier* than our current *now*, and both contribute to our memory of these earlier events. However, upon closer inspection we determine a clear distinction between the two and how their contribution to our memory. With hindsight we reflect upon previous *instants* through experience in the present. The use of analepsis in a narrative, however, usually involves presenting events from the past to explain events occurring in the *narrative now*. Hence, analepsis can often be seen in the form of the past informing the users understanding of events in the "present" (i.e. the *narrative now*.

It might be argued though, that analepsis, like hindsight, attribute to our memory of the past (, and as such inform our anticipation of the future. If we accept the idea, that the narrative is consumed in the physical *now*, it can even be argued that everything in a narrative is a description of past events, and as such it is the information we gather in the *now*, that informs our perception of all events in the narrative, disregarding if these are presented as an anachrony or not, and as such informs our anticipation of the future. By this, any narrative consumption can be regarded as following the previously proposed feedback loop between experience in the present, hindsight and foresight.

By examining prolepsis in relation to foresight, we likewise similarities as well as discordances. With prolepsis the user is in one way or another *presented* with information concerning either possible future events, or "actual" future events. That fact that prolepsis can present things that *will* happen in the narrative, suggests a discordance to the workings of foresight, as we have previously argued that, as with time itself, we can never use foresight to envision the future in absolute, but only *predict* possible future events and their possible relation to one another (before/after) based on previous experience.

However, like with foresight, it can be argued, that the user can never be certain if these potential events presented by prolepsis will be actualized, but in the "contract" between the author and the user, there is an informal expectancy that the things presented will be relevant, even important, to the story. As such, Ricoeur also states that "[t]o follow a story is to move forward in the midst of contingencies and peripeteia under the guidance of an expectation that finds its fulfilment in the "conclusion" of the story"[67, p.66]. This also follows the notion that "life cannot be told exhaustively [..], and narrative therefore has to concentrate on the choice of significant episodes that establish a configuration and meaning"[40, p.609], which in turn fits with the previously presented argument by Ricoeur, that the *episodes* "must finally be acceptable, as congruent with the episodes brought together by the story"[67, p.67].

To conclude this section, we argue that, even though we have described how it can be said that there are similarities as well as discordances between hindsight/foresight and analepsis/prolepsis, in respect to how the mind organizes these narrative events through the duration of the narrative, analepsis and prolepsis can be regarded as mainly narrative devices to filter information to the user in a controlled manor, but the registration and perception of said information, follows as a consequence of hindsight and foresight.

4.3.3 Narrative affordance

Narrative affordance in broad terms could be seen as ”an invitation to an action” [92], as to how an object can be used. This was first presented by Gibson in 1979 [92, 45], where he clocked the term ”affordance” to perception. The term evolved through time, as times changed and the term got connected to interactive media by Mateas (2001) [92, 57], who also connected it to agency. Because as the user gets power to do things and thereby change the narrative by taking action and changing the narrative with their intentions and actions. What is interesting about affordance in narrative is that we can connect it to foresight - as it is connected to what the player or participant expects will happen when they interact with certain items or objects in the environment. However, in the article by Young et al. [92], they also argue that affordance can also be related to events rather than just objects. As certain events will prompt the player or user to do certain things or complete certain tasks [92]. Events can also make the player think about what will happen next in the narrative [92], and how they should proceed in their quest - which we then argue closely relates to foresight. Therefore we should take the *narrative affordance* into consideration when we design the narrative. We can utilize events or the narrative trajectory in order to make them experience foresight at certain points in the narrative.

4.3.4 Interactive storytelling

As mentioned in the section above, interactive media is when the user is being empowered so that they can influence the narrative in some shape or form. In the paper by Adrian Jones [4], he suggests that due to the nature of interactive narratives, the structure of a narrative should be adjusted to the affordance of the media. He suggests three types of approaches to narratives which can work with the interactivity [4]:

- Branching narrative: Which like the name implies branches. The branching happens when the user makes decisions in the narrative - But due to the exponentially of the outcomes, most narratives using thing approach is limiting the branching itself in some shape or form [4].

- Exploratory narrative: Where the user explores a virtual environment and the stories in the environment, the story can be an overarching narrative which is at the end put together by the user [4].

- Generative narrative: Here the narrative can be an emergent property of the interaction made by the user.

For this project, we need to decide how much freedom we should give the user as they are going through the narrative - and how the interactivity should work.

4.3.4.1 Narratives in Virtual reality

Even with the topic being interactive narratives in virtual reality, the world of 360 narratology fills a great deal of the void which is the limiting range of academic research in this field. Furthermore, research into 360 video shares many of the same elements as an interactive 3d environment in the context of user attention as well as understanding of a free, exploratory scene rather than a linear narrative, though there must be complimentary research on the interactive aspects of virtual reality. Bala *et al* [12] researched, as well as other topics,

attention in 360 video and how users utilized different senses to perceive the narrative to experience the scene in an expanded way, compared to a 2d film. They discovered that while all users were viewing the story from the so called directors cut, how the movie would have been framed if it had been a standard 2d medium, a third of the users started to look onto other regions of the 360 scene.

The researchers furthermore noted that most users split their attention between visuals and audio, listening in on the conversation of the characters in the scene while looking elsewhere [12].

While Bala *et al* [12] argues that virtual reality developers should utilize lighting to draw the attention of users [12, 46], as they found it a successful technique, it is conflicting with the internal team of Oculus [59], a subsidary of Facebook who produces virtual reality hardware and services.

They state that while it is seen as a normal practice to manipulate the user with techniques such as lighting based guidance, it never fully, and merely helps to undermine the potential and freedom of virtual reality, in which they argue it is more sensible to even use the medium if one is to control the user anyways, rather preferring what they call "The Letting-Go" [59].

From a traditional media studies point of view, this is a logical reasoning, as each medium stands on its own merits, although still with roots back to the legacy media it sprang from, in this case games, which yet has roots further back [36, 82]. Therefore for this project, depending on the narrative structure it should be noted that it can be hard to control the user in the experience, while with the 360 vision it can get hard to guide the user to see something which is directly behind them. With the exploratory narrative however, we could argue that we only need to make sure they know which items drive the narrative, and then they can find them at their own pace - so maybe the order of the story is not important its rather how they fit together in the end.

This is also interesting while we are interested in foresight and hindsight, more specifically the moment in which the user experience it. If the user is set to explore an environment and find the story, they would per story object or event get new information which would lead to either foresight or hindsight. But how does the brain interpret a story?

4.3.5 Narratology and Cognitive science

When subjects are reading a narrative the appropriate areas in the brain light up; when reading about going from one room to another the area which is associated with spacial scenes light up, and when certain objects change after interaction from a character like turning on a light - areas associated with the grasping motion lit up. [71]
She also expresses some pessimism regarding cognitive science and she asks what it can give her as a narratologist. She also compares it to the physicist's theory of everything, whereas they cannot see what is happening in detail - like individual neurons, only which part of the brain "lights up".

However, Ryan also mentions that from a narratological standpoint, MRI are in a no-win situation - whereas when it disproves theory it is useless, and when it fully proves the theories then it is redundant.[71]

She then goes into Herman's theory of the nexus of the mind, which defines objects of cognitive narratology: The minds of characters, the mental activity of the reader (spectator, player, etc), and narrative as a way of thinking (or the importance of the narrative for the life of the mind) [71]

4.3.5.1 Herman's theory of the nexus of the mind

[71] The nexus of the mind and narrative can be broken down into three categories; the mind of characters, the mental activity of the reader, and the narrative as a way of thinking [71]. The following section will describe each of the categories in order to understand how Herman s theory can be used for the design of the narrative experience.

Firstly there is the mind of the characters, is where narratology, narrative cognition as well as psycho analysis is combined into the notion of the mind is seen as a secluded inner domain where subconscious processes takes place. These processes include; dreams, desires, illusions and obsessions. Narratology added to these a collection of techniques with with the mind can be represented in interiority and in secret. These techniques were stream of consciousness, psycho-narration, and indirect and direct discourse, as well as a hybrid free indirect discourse. Another method is the use of the omniscient narrator, who works as a MRI for the "inner life" of the characters on the level of symbols and images [71].

However it should be mentioned that usually we get to understand a characters state of mind, rather through action than a description of the character's thoughts. [71] The state of mind, much like the subconscious process, is the desires, goals, believes and plans of a characters. These are often connected to the plot - so in order to understand the plot of a given narrative we must understand the state of mind of the characters and their actions. These are in successful narratives according to Ryan mostly implicitly stated. [71]

Secondly there is the mental activity of the reader. Ryan [71], goes into three methods with which it is possible to measure the mental activity that happens when exposed to a narrative. The first of which is the use of MRI, where the electric reactions in the brain is measured in order to see which areas of the brain is activated. However the method needed to extract the data causes the reading to be unnatural, while it is necessary to control the temporal flow by presenting the text, word by word instead of the text in its entirety - in order to take individual reading speed into consideration. This limits the effectiveness of the experiment and its ability to capture the brain activity created as a result of the narrative. [71]

The second method is by creating an experiment. Ryan [71] specifically describes an experiment where the focus is memory and and understanding of a text. Participant were after they had read the text, asked to press a bottom every time they felt an event had taken place. The narratives would be specifically composed so that they could test fast reaction, more precisely, narratives which no one would read for their interest in the narrative. [71]

The final method is the least dependable according to Ryan [71], while this method uses the users own words on how they experienced the narrative, rather than numerical measurements. Roland Bathes deemed this method the most effective in order to capture "pleasure of text" while it catches the real reaction of people. [71]

Lastly there is the narrative as a way of thinking, which steps away from the decoding of the narrative and goes more into the mind of the one who conceives it. Here it could mean the author as they conceive the narrative with a meaning, however we also conceive stories as a way of communication; "telling stories", while many people see themselves as narrative constructs which then relates the the narrative as a way of thinking [71]. This area not only deals with the act of telling stories, but also its importance in terms of us as humans creating social connections. This notion is not something new as it has before been suggested by several different theories that we as human memories take narrative form. One of the theories was suggested by Roger Schank [71, 91] in his book *"Knowledge and Memory: The Real Story: Advances in Social Cognition, Volume VIII"* [91]. Another theory by Mark Turner states that we developed language in order to tell stories [71], and later David Herman suggested that a narrative is something we as humans need in order to have an experience, while a narrative affords experience [71].

4.3.5.2 Anticipations/Expectations

As we think in narratives or stories [50, 15, 68, 3], we use this in order to anticipate the future and make decisions based on the possible outcomes. This can be called anticipation. G. Liveley [50] made an extensive literature review looking into anticipation and narratology. As quickly mentioned we will make stories where we can, and we will also categorize these stories according to their significance as well as their temporal-causal links to other events as well as future outcomes [50]. We also use our previous experiences to make logic and rule to plausible motivations and actions of other people or agents [50]. This notion has long been assumed by narratologist, but also modern narratologists have taken this notion as corresponded it to cognitive science - so not only from a narrative standpoint. Maintaining the notion that we perceive the world "narratively" - while we narrate or perceive events in the real world as narrated [50].

As one of the basic dynamic drive forces in narratives, Anticipation allows us to make temporal-causal links which can motivate the narrative. The links also connects separate events, which can connect the past, present and future, as well as putting a pattern to them [50]. Anticipation is very much the notion of "what if", which is a speculation we all know from everyday life - however it is also something which is used in narratives, where we, a character or the narrator can present or imagine possible futures or outcomes [50]. In narratives or stories the author or creator can also use foreshadowing as to induce anticipation into a story [32]. Foreshadowing are advanced hints which helps set up expectations as to what is to come [32, 31]. Foreshadowing can also create some form of hindsight, as it can make event seem credible, due to them being set up beforehand, with suspense and anticipation [32, 31].

We would like to suggest that anticipation can be connected to foresight. While foresight and anticipation both deal with the "what if" scenario and possible outcomes. This would also connect foresight to hindsight, while we connect future, present and past with anticipation.

4.4 Analysis conclusion

In this analysis we have researched foresight and hindsight, as to how each might be characterized, and gained an understanding the potential cognitive functions associated with them. Our research indicates that hindsight and foresight are some of the basic workings of our consciousness and hence essential for our understanding of human cognition (see section 4.1).

In the analysis, we have presented how it can be said, that we humans use our understanding of the past, in the present, for imagining the future, and as such, we argue for a view of hindsight and foresight, as an ever changing circle, a constant feedback-loop, in which they mutually inform one another through experience in the present (see fig. 5).

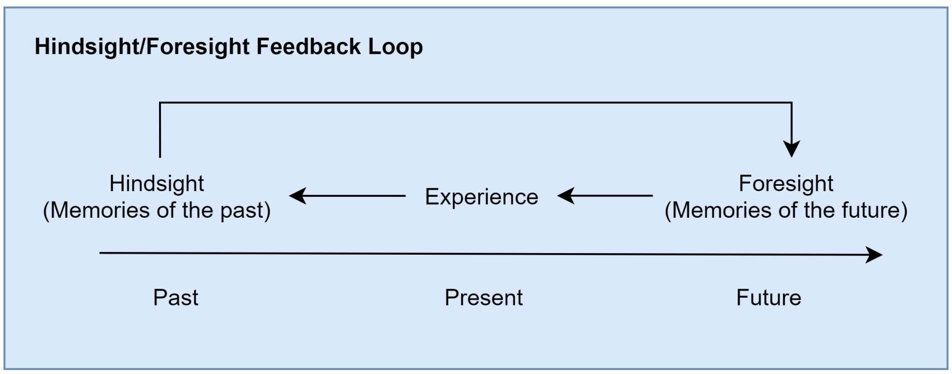

Figure 5: *Hindsight/Foresight Feedback Loop*

As such, we argue that the present serves as a filter through which we, by hindsight, continuously "map the present onto the past"[49, p.112], which subsequently informs our foresight, since "[w]hen we retrospectively re-configure our past by endowing past experience with new meaning, we re-configure our future as well" [48, p.646](Though claimed by Freeman (2010, p. 190)).

As we previously established how anticipation can be regarded as taking the present and past into consideration in terms of what will happen (see section 4.3.5.2), we argue, that foresight can be regarded as our expectations or anticipation of future potential "instants" preceding the present, based on our understanding of the past. In the present these expectations are then either met or unmet, through experience, by which we consequently reflect upon this realization and through hindsight, we reevaluate the "instants" in the past (see section 4.1). This constant revision of events in the past based on experience in the present, leads us to the connection between memory and hindsight/foresight. For this, we adopted the notions of *memories of the past* and *memories of the future*, to signify the similarities between hindsight and foresight. *Thinking* about the past and *imagining* the future can thus be seen as similar actions, as "the past can only be reconstructed by the imagination"[67, p.82]. As we visualized in fig. 2, our memories of the past is continuously informed by our experience in the present, as the (potential) memories of the future becomes actualized in the present. In other words, as the "instants" of the future transcends through the present, they immediately become memories of the past, as the experience is added to our cognitive library of memory (be it semantic or episodic or both). This new memory then informs our perception of all other memories of the past, thus potentially altering our understanding of the nature of these memories of the past. From the analysis of hindsight and foresight, we

thus propose, that there is an evident connection between the cognitive functions of memory and of hindsight and foresight. With our adoption of the concepts of *memories of the past* and *memories of the future*, we argue, that this similarity between hindsight and foresight is further established. To further enlighten this interdependent relationship between

hindsight, foresight and memory, as well as their connection the way in which we envision humans perceive the world - through narratives - we examined the concept of *time* from both a phenomenological point of view, as well as from a narratological point of view. Based on this, we suggested that our perception of time, both through narrative worlds as well as our "real" world, can be argued to happen based on causality and interrelations rather than through a measurement of time (see section 4.3.1). The Aristotelian notions of *instants*, *befores* and *afters* serves as a general foundation, for our framework, as we established how any "instant" can be regarded as both a before and after. We therefore argue, that this view of time, supports the notion that our memories are organized relative to causality. With this focus on causality between our memories, is further supported by Aristotle's focus on 'change' as a main pillar of time. We argue, that the views of Aristotle, further establishes

our understanding of memories of the past and memories of the future employing similar cognitive functions. However, this view does not sufficiently account for the 'present' in which we experience. As such, we combined the above with St. Augustine's view of time, from which we adopted the tripartition of time into *past*, *present* and *future*. By this, we are able to separate the *potentiality* of the future, from the *actuality* of the past, and the *elusiveness* of the present. As such, we are able to introduce a tangible 'line' separating the memories of the past from the memories of the future.

By combining all the above, we are able to further expand upon the workings of the previously suggested Hindsight/Foresight Feedback-Loop model. As can be seen in fig. 6, we propose a framework for characterizing hindsight and foresight, in which hindsight occurs as a function on the memories of the past. As new memories from experience in the present is added, we both reflect upon the position of this new memory (information/knowledge) relative to its causal connections to the existing memories, as well as our understanding of existing past memories in light of the knowledge gained from the new memory. After this revision of past memories and the appropriate placement of the new memory, our revised *combined knowledge* then informs our expectations of the possibilities of the future, and as such our foresight. As with memories of the past, these memories of the future will then accordingly be modified based on our revised knowledge-base. As the future gets actualized as *experience* in the present, we can further expand upon this *experience*. Immediately preceding the experience in the present, we have an expectations (or anticipation) based on h

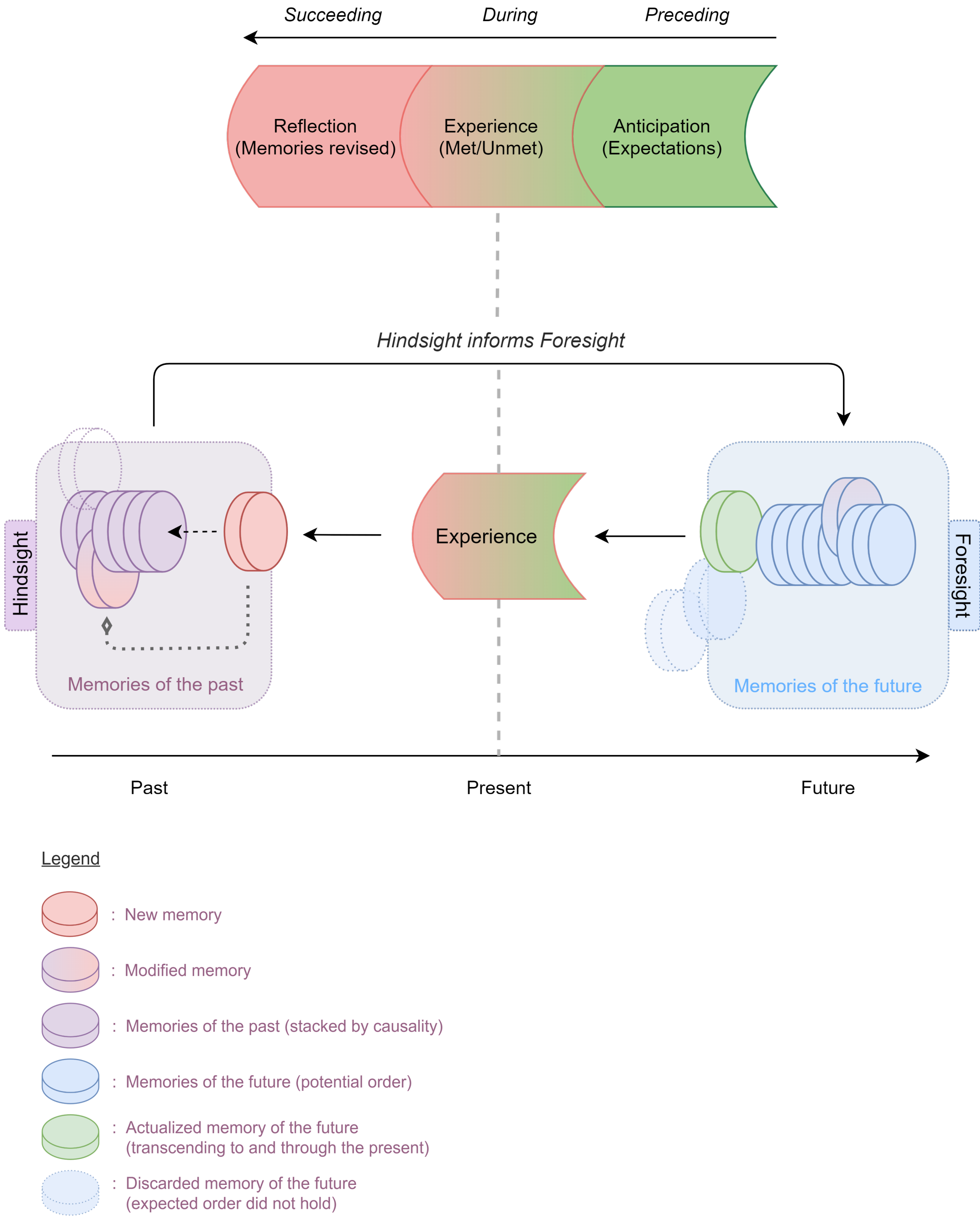

Figure 6: *Hindsight/Foresight Feedback Loop - Expanded*

the memories of the future, of what will occur, and how our sensibilities will perceive this. During the *experience* in the present, our expectations are then either met or not. Immediately succeeding the experience, we reflect upon the experience, as it transcends into the memories of the past, and thus inform our hindsight.

4.4.1 Hindsight/Foresight Feedback-loop model in practice

From the conceptualization of hindsight and foresight, through the proposed framework of the Hindsight/Foresight Feedback-loop model, this study seeks to explore these cognitive functions in relation to narratives in mixed realities, and more specifically to narratives in virtual realities.

As our interpretation of our memories might be biased and even changed without us being aware of it, our foresight might be born out of "wrongful" hindsight, because we think that "we know we know" while in fact we "do not know that we do not know". Thus, foresight and hindsight can easily be manipulated or changed, so the 'truth' can only be found in the moment, i.e. in the *instant* (see section 4.1.1.1 and 4.1.1). In order to obtain the instant in time in which hindsight or foresight is utilized, we argue, that one can make use of a controlled narrative, where we can control what happens and make use of narratological tools in order to predict when the participant might experience foresight or hindsight, as we have shown that these terms are not new to narratives (see section 4.3.2). As such, analepsis and prolepsis are thus regarded mainly as control devices to provide information to the user in a controlled manor in a narrative. The experience and the storing of said information follows the theories of foresight, hindsight and memories (see section 4.3.2.3). This would indicate, that we should be able to use analepsis and prolepsis in order to 'provoke' either foresight or hindsight. As the study has a strong focus on theories of cognition, it can be argued that the study relates to cognitive narratology. In this regards, we take note of a specific criticism towards the field, given by Ryan [71] (see section 4.3.5), as both fields does not seem to gain anything from each other - other than what they already know. However narratology and cognitive science does seem to connect on a few areas (as established previously), since they share some of the same terminology as mapped out by Herman [71] (see section 4.3.5.1). Characters in narratives are real people in the setting of the narrative, this also including their goals and motivations, which builds on their experiences, which we argue to be connected to the cognitive science with memories and foresight and hindsight. We likewise suggest that especially anticipation (as a narrative tool), is strongly connected to foresight (see sections 4.1, 4.3.2.2, and 4.3.5.2).

Following the notion that narratives are how we perceive the world, we argue, that examining hindsight and foresight in a fictional, 'artificial' environment containing a prescripted narrative, will be able to provide information on the workings of hindsight and foresight in the 'real' world (or any other for that matter). To simulate the 'real' world as best as possible though, we will use an interactive narrative in virtual reailty in order to do this, and there are different ways in which we could use interactive story telling, where we could either have a branching narrative, exploratory design or generative narratives 4.3.4. An approach could be with an exploratory design, where as certain events or object could give the player hints as what the narrative could be, relating to their foresight, which would then become hindsight as they progress through the narrative 4.3.3.

4.4.1.1 Hindsight/foresight feedback loop model internal test

Before applying the framework to a larger pilot experiment, we decided to do a small test of the model, on written narratives. Hence, we did a very simple test between ourselves, where we each chose a novel from a free short-story website [1]. We each chose 1-2 short-stories, depending on the length of said short-story. Then we individually went through the story with the Hindsight/Foresight Feedback-loop model as a template. Each outcome can be found in appendix no. 1. This was done in order to test if the model was in fact applicable to different narratives.

The results showed clear indications that hindsight and foresight is connected as we hypothesised with the model. We did however find that we did have different focus points when we visualized the model, which lead to different depictions of the narratives (however all through a flowchart). We also tried to do an analysis cooperatively and through a spreadsheet, instead of a flowchart in order to gain a better overview. The flow charts and notes can be found in appendix no. 2.

4.4.2 Final Problem Statement

Based on our analysis, the final problem statement is as follows:

> *To what extent can activity of the Hindsight/Foresight Feedback-loop, be detected in an interactive virtual experience using psycho-physiological measurements?*

5 Methods

The goal of this project is as mentioned to explore the possible visualization and an indication of when we experience hindsight and/or foresight. Our research shows that there are different psycho-physiological measurements which could be indications of this. This thesis and appurtenant experiment has its focus on eye tracking, as one of these measurements. The following section will therefore go into how we can use these measurements to perceive, hopefully, hindsight and foresight in a narrative according to our Hindsight/Foresight Feedback-loop (see figure 6). We will also be taking subjective measurements as to get the participants thoughts on the experiment and how they perceive the narrative, this is explained further in later sections. It should also be mentioned that this project is exploratory, meaning that we seek to see if there is an indication or tendency at all - which could then later be fully explored.

In this section we will go more into which data types and measurement would be applicable in order to answer our problem statement (*See section4.4*). Another subject which will be covered in this section will be technical requirement for the equipment which we will be using. Furthermore we will cover the psycho-physiological measurements, in this case; eye tracking data, which include pupil dilation, areas of interest, and sacades.

We decided early that we would be making a virtual reality prototype. This was partially due to the groups general interest in virtual reality, but also due to the acquirement of the HTC VIVE PRO EYE to the Augmented Cognition lab, at Aalborg University Copenhagen. We will go more into specifications of the headset and software in the following sections.

We will also have a look at subjective measurements, which in this case we will be explaining how we plan to use interviews during the experiment, and how they can help us in the analysis of the aforementioned eye-tracking data.

5.1 Technical requirements for Virtual reality

This section of the report will go into the soft- and hardware which we will use for the prototype and thereby for the testing.

5.1.1 Virtual reality: Hardware and Software

To conduct an experiment in virtual reality we need either an autonomous VR headset or a combination of a VR headset and powerful PC to render graphics. As mentioned, in our case, we have a HTC Vive Pro Eye, the latest iteration of premium type VR headset from HTC. With the addition of in-built eye tracking technology which allows us to record and/or observe where a person looks at (gaze), pupil dilation, pupil position, and eye openness [85]. The headset features 120Hz tracking with a accuracy for 0.8^{o}-1.1^{o} and it works at its best using NVIDIA Variable Rate Shading (VRS)[10, 85]. This kind of headset needs a powerful PC to render the graphics as it, by itself, does not have any hardware for rendering environment. In our case, we have full tower PC with Intel xxxx processor and Nvidia GeForce 1080 to render and run the virtual environment we have built for the experiment, the PC should therefore be sufficient to run the experiment.

Latency and frame rate are bot important factors in combating motion sickness, as well as to not break the relationship between reality and the simulated world the user willingly submerges themselves within while adorning an HMD [23]. Frame rate itself means how many frames are rendered per second, with each medium and industry having a different standard. Latency on the other hand surrounds user input, as it is the delay between action and reaction, how many milliseconds it takes for a system to take input and in return answer the user.

Elbamby *et al* states that a rendering latency of more than 15 ms can be a cause of motion sickness [23], which furthermore is the minimum for a true interactive experience, according to Robin Thunström, while the experience can be recognized as interactive at merely a frame rate of 6Hz [60]. Naturally, a lower rendering latency than the minimum would be

preferred, though the currently available technology is the greatest barrier, especially when looking at wireless virtual reality HMDs. While Elbamby *et al* would propose to wait for 5g wireless technology, the Vive Pro claims proper, although short ranged, wireless virtual reality experiences with "near-zero latency" [86]. Current 4G wireless technology puts a strain of around 10-15 ms on the display rendering [23], which requires that more output from a computer to reach the minimum required framerate.

When debating the topic of cybersickness, which is bad enough on its own, it is also in relation to topic of presence. Riches *et al* found that cybersickness, as well as many other factors, decreased presence in users [65]. Even though presence is not the topic of investigation, a detachment from the virtual reality will make the entire experience, and thus experiment, inferior. It is therefore worth mentioning, and something we should be aware of.

5.1.2 Illusion of agency

One of the greatest obstacles in interactive narratives is, naturally, to truly make them interactive. But to create a story in which the player not only observes, but influences, would require an exponential amount of content, depending on the size of the game as well as type of story[27] [87].
A game like Facade has several outcomes, all depending on the players choices and input, even though the individual engaging with the game might not realise this. But the overall technical quality of facade is rather low, considering it came out in 2005. Beyond that, the length of a play through is not even fifteen minutes, which might not be very attractive for most consumers, when there are games which claim freedom of choice, as well as 10+ hours of content.

Another far less elegant solution, but one which has a long tradition, is lying and creating an illusion of agency.
Fendt *et al* argues that the illusion of having agency over a game has the potential to elicit as

strong a reaction as actually having full agency [27]. The hypothesis is that system feedback to the player at key points, during decision making, will ensure this feeling, which is also their conclusion.
Many large games have been sold on this claim, such as the now defunct Telltale Games which sold many games which claimed to log and react reactions, with the strongest of their titles being The Walking Dead according to Sarah Stang who claims the illusion is strongest, because of, she argues, the characters and original narrative [74]. Returning to the research

of Fendt *et al*, their findings on direct feedback, as well as callbacks to decision points does not mention a limit of when the illusion shatters, although they did find that barely any feedback, as well as none, did end with an overall lower sense of agency.
It is acceptable to suppose that "as high as possible" amount of feedback and callback is the way to go, seemingly without any reasonable upper limit.

5.2 Psycho-physiological Measurements

Based on our research, we have found some psycho-physiological measurements, which could be interesting to use in order to maybe find an indication of foresight and hindsight. With the eye tracking capabilities of the HTC VIVE PRO EYE, we looked at what data types would be available to us (*see section 5.1*). Now what can these data outputs be used for? The following sections are going to explain it.

5.2.1 Eyetracking

Eyes measurements such as pupil dilation, sacades length, fixation, area of interests are currently popular psycho-physiological measurements to indicate person's cognitive load, attention, indication of pain or drug usage [42].

5.2.1.1 Pupil dilation

Pupil dilation as a source of psycho-physiological measurement on the ground level is showing how intense the light is in the presented environment. Because of that pupil's are being named as gates or roads by which lights are entering our brains. But changes in pupil's radius is hinting more information than just changes of lightning of the environments.

It's been found out that two muscles types, located in pupil are being controlled by autonomic nervous system, which has two separated divisions: sympathetic, that controls muscle called dilator pupillae, and parasympathetic, which control sphincter pupillae. Sympathetic division prepares body for emergency situations when parasympathetic division is controlling body during ordinary times. In case of pupil dilatation, the sympathetic division, as a result of raising awareness during stressful situations, dilates the pupil, when parasympathetic one constricts the pupil. Therefore, we can argue that changes in pupil's diameter can hint mental workload, cognitive overload and other changes of humans cognitive processes.

To register such changes most of eye-tracking hardware that uses pupil dilation as either part of calibration and eye-movement registration process or as separate parameter uses horizontal pupil diameter as variable as vertical diameter is too sensitive to blinking or in other words to eyelid closure. Therefore, it was argued and discovered that usage of horizontal pupil diameter is still have some biases as it either overestimates or underestimates pupil diameter in the upper-right or lower-left corner, depending on the hardware [42]. Also, the camera-based eye-tracking systems might introduce noise if eyes are moving forward or back as pupil diameter is being calculated based on pixels from camera's video input and it is recommended to have a recordings with fixed distance between camera and eyes for better data quality.

Before moving to what cognitive states or changes pupil dilation might record, it is important to state that effects, evoked by cognitive processes are small and can be easily overshadowed by larger effect of light intensity. To avoid such artifacts it's being recommended to have a baseline with several different luminance, but it's also that it is hard to control luminance in studies when there is a natural variation of luminance. In addition, Laeng *et al* [42] found that pupil diameter might be influenced by illusion of brightness which might hint that it's not luminance that matters, but subjective experience of it. For cognitive experiments, as matter of fact, it stated that moderately lit rooms or environments are best suited for cognitive experiments as it includes work of both presented muscles.

Returning to the baseline, it's recommended to have a longer recording of fixating on blank screen. Also, if the experiment consist of several different stimuli, it is advised to have 2-3s of breaks for pupil to return to it's base level.

Another way of analysis pupil's data would be using the pupillary unrest index which includes absolute values of cumulative changes in pupil size. It's also stated that pupillary index does not vary with luminance. Hence, to compensate that several algorithms were introduced, but compared to baseline option, the pupillary index although is being linked to cognitive activity, it explains smaller portion of variance of the data, compered to first option with comparing pupil's diameter against baseline. According to numerous researches, different states or proccesses affect pupil's diameter:

- Cognitive overload,emotions, pain, drugs are increasing pupil's diameter.
- Fatigue, diabetes and age is decreasing pupil's diameter.

Several findings related to cognitive tasks to increase pupil dilatation shows that more complex cognitive task as memorizing more complex numbers or doing more complex math operation would co-respond to higher values of pupil dilation. In other words, the higher is level of effort needed for a task, the higher the rise of pupil diameter compared to baseline is. Also, interesting finding by van Orden *et al* [42] shows that while blink rate, blink duration and fixation duration tend to decrease as result of increased workload, the pupil dilation tended to continue growing.

As emotions are reflection of cognitive processes and autonomous nervous system, the emotional arousal is being reflected on pupil's dilation. It was tested using different kind of stimuli such as photos and sound that elicits emotions, pupil size of other person, etc. [42].

To sum up, the pupil dilation reacts not only to lumination changes but as well to cognitive processes, evoked by autonomic nervous system and we believe that pupil dilatation might be interesting parameter to use for defining the intensity of cognitive load and as a result usage of hindsight or foresight.

5.2.1.2 Fixations and Sacades

As was mentioned before, building the experiment around pupil dilation is complex as it needs a lot and preparation and clear baseline/calibration as the cognitive changes, affecting pupils might be overshadowed by light intensity. Other parameter that might show cognitive processes are sacades. But before defining sacades, we need to introduce part of sacade definition which is fixations.

Fixations is eye state when it's remains still for longer period of time. Time may vary between 100 ms to several seconds. During this fixation time eye is not completely still, but produces small movements that are classified as tremor, microsacades and drifts. Drift is a small movement that moves eye from center of fixation and microsacades are the ones that compensates drift by returning gaze to the center of fixation. It is important to mention that tremor is slow movement when microsacades are quick ones. Om other hand tremor is small movement which does not have any particular role and is mostly linked to imprecise muscle control.

Fixations defines start and the end of saccade as saccade is being defined as rapid motion from one fixation to another. The saccade is being named as one of the quickest movement human's body can complete as it takes roughly 30-80ms to complete a saccade.Although, some studies argues that there is a delay for saccades such as "reflexive" saccades as before moving eyes the brain are evaluating not only where to move eyes but also if it's worth to move then into target location [43].The transition of these kinds of saccades are believed to be 200ms instead 30-80ms. Saccade as movement has several properties that defines the saccade: onset, latency, amplitude, angular direction and direction towards location(s).

The main variable that is being observed in studies are saccade rate which measured in number of saccades per second. It was found out that saccade rate is decreasing while the difficulty of task is increasing [42]. In different study it was found out that increased in arousal level increases the saccade rate. In this examples it is important to mention that fixations are playing important role as increased or decrease of saccade rate is increasing or decreasing fixation rate or fixation length. In Szumowska *et al* [26] study about cognitive closure are utilizing both fixation ratio as well as dwell times for indicating how much attention was spent on main and second task in relation to need of cognitive closure (NFC).

5.2.1.3 Areas of interest (AOI)

Moving from sacades and fixation, the next interesting data that can be gathered from fixations and sacades is Area of interest (AOI). AOI is defining regions in 2D space where researchers are interested the most or it is the regions which are the most popular according of eye-tracking data. Area of interests as heatmaps shows if participants of the experiments were looking where researchers were expecting them to look and in addition to that they can extract the types of eye movements inside particular AOI.

Furthermore, AOI allows researchers to extract simple data as dwells, transitions and AOI hints, that later can produce complex variables such as entropy or string-edit measure. AOI's are mainly linked with usage of visual attention and attention as a whole[42], but most studies show that instead of attention, there is strong correlation between AOI dwells time and memory and interest. Therefore, it is stated that usage of AOI as main variable of problem statement requires a lot of attention from planning the experimental design as there is lots of assumptions about AOI that might be not valid. One of those can be that person can be looking on one object at the time, but in reality you might focus your attention far away from your fixation point. As an example, driver of car are always paying attention to the car driving in front of him, but at the same time driver might focus on the driver of the car, even though fixation point does not hit driver at all.

The dwell, mentioned before, represents the the eye gazing or eye movements starting when gaze enters defines AOI and ends when it exits the AOI. The dwell has several variables such as enter and exit points, duration between enter and exit, etc. For the experiments, the AOI are either being defined by experts by their own experience and expectations or by having software-generated AOI based on scene stimuli or gaze density across the screen. These kind of AOI's can produce several types of AOI or even combination of those based on experiment, that is being conducted. Several examples of AOI types are planes, dynamic, gridded and distributed AOI's. Although, we believe that in mixed reality studies AOI as parameter is hard to use for several reasons:

- The environment is constantly changing which means that 2D based AOI's are unable to show the interesting areas or unable to compile proper ones.

- Mixed reality introduced the 3D environment which means 2D AOI's should be replaced by 3D AOI's. In our experiment 3D AOI's are being replaced by 3D objects itself.

Although, the usage of AOI is popular among attention based researchers as it supplies with visually readable information if experiments are being conducted on 2D screens, but the head/eyes fixations are needed because of the same reason as pupil dilation.

To sum up, the mentioned eye-tracking data variable might be useful to indicate hindsight or foresight by having indication of increasing cognitive load that pupil dilation and saccade ratio can show. As for this work, the main focus will be on pupil dilation as main variable to indicate fastforwards or flashbacks on cognitive level.

5.2.1.4 Hypothesis

Based on the previous sections, it is our claim that the participants will have an increase in pupil dilation when the Hindsight/Foresight Feedback-loop is activated.

Research Hypothesis:
H1: There is a significant difference in the participants' pupil dilation (increase), when the Hindsight/Foresight Feedback-loop is active.

Null-Hypothesis:
H0: There is no significant difference in the participants' pupil dilation (increase), when the Hindsight/Foresight Feedback-loop is active.

5.3 Subjective measurements

In order to further find sections in the game, where we would expect the EEG to show, some differences in the the frequencies, maybe some synchronisation and desynchronisation. We have decided to use subjective measurements as a supporting type of measurement, more specifically; we have decided to use interviews. We wanted to get the users input as to what they story is about, as well as where they change their perspective on the story.
We firstly considered doing this, using a questionnaire after they have completed the story, but we were concerned that they would not remember when they changed their perspective on the story after the fact. Therefore we decided to do the interview during the experience, as to get their perspective as they were experiencing the narrative, presumably catch the moments when they would change their expectations, as well as their perception of the narrative - or at least get a better estimate of when they would change perception.

5.3.1 Interviews

We want the questions to be open, while we want their immediate thoughts, as well as encourage them to expand on their answers. We need to decided what type of interview we are going to use. We know that they will be in person, and we are going to interrupt them during the experience. There are different ways to structure an interview; structured, semi structured, and unstructured interviews [81]. These three types will be quickly described, followed by a conclusion as to what method we are going to be using.

5.3.1.1 Structured Interview:

The structured interview is the most rigid interview method. The questions are predetermined based on a clear goal concerning the information sought. The participant is also not really prompted to reflect on their answers, as the questions are mostly close-ended and read exactly as written [81, 72]. This also makes it the most quantitative of the interview methods as well as the easiest to replicate - both for later test as well as between subjects. The main problem with this method however, is that it is so rigid, as well as value the right response over the interesting response, also meaning that we cannot stray from the preset questions no matter how the conversation evolves. This is opposite to what we want to use the interview for [81, 72].

5.3.1.2 Semi structured Interview:

A semi structured interview works more like a guided conversation [81], where the interviewer can have some questions prepared beforehand but still have the freedom to probe when something interesting turns up during the interview. This however can lead to it being difficult to compare answers while the interviews might differ in length and in some of the content [81, 72].

5.3.1.3 Unstructured Interview:

These types of interviews are more like actual conversations compared to the semi structured interview which is a guided conversation. This type of interview is a conversation with an underlying theme [81, 72]. This however present aforementioned problem with different interview time and content even more so than the semi structured interview. It it also considered a less reliable method compared to the two others [81, 72].

5.3.1.4 Sub conclusion:

After this quick description and research, we decided to go with the semi structured interview. Meaning that we will have a set of predetermined questions for the interview, however we will be allowed to ask the participant to elaborate, or answer follow up questions. We will use the interviews to support the findings we hopefully will get with the Eye-tracking. The answers from the interview will hopefully get their impressions as they change, and maybe help us to get an ideas as to what will make them change their perception of the narrative. It is important that we let them have time after they have read the notes, before we ask them questions, while we want them to process the information given to them. We also need to decide when we should ask them - do we ask them after every story event/object, or do we cluster them together. An idea could be to categorize them in scenes, so that every room or section is considered a scene which hold certain items. Then we could also ask them as they are leaving a scene, as to not disturb them as they are processing the story. Then we "disturb" them as they are going from one scene to another.

6 Experimental design

6.1 Software and hardware

To prove the concept of hindsight and foresight, the interactive experience needs to be implemented. The main building component was chosen from a group of game engines such as Unity, Unreal and Godot. As most of the group has worked with, we choose Unity as our main implementation environment. Where the main programming language is C# with usage of Microsoft Excel for data visualization.

To enable eye-tracking in HTC Vive Pro Eye, we considered SDK's from both HTC and Tobii. In order to get the eye-tracking data from the virtual reality headset we are using VIVE SRanipal SDK and for reading the eye-tracking data we use the Tobii XR SDK is being used. Both SDK's are provides Unity packages which allows us to import all needed scripts and systems as assets. For the interactive experience in VR we are also using SteamVR libraries, which includes different types of interactions, movement and other extras that might be useful while implementing a VR-experience.

For hardware, we are using a tower-size personal computer, which includes Geforce 1080 graphics card(GPU), Intel i7 7700k central processing unit(CPU), 16GB of random access memory(RAM) to have more freedom for level creation as VR, like a standalone 2D-3D game has technical restrictions for rendering if the number of triangles exceeds the calculation limitations of the hardware. As HTV Vive Pro Eye already has headphones included, we don't need a separate set of speakers or headphones for the experiment.

6.2 Technical requirements for VR

6.2.1 Foveated rendering

One of the largest issues of modern virtual reality, is the computational cost simulating reality, and having a high enough frame rate, resolution, and having a more lifelike arc-minute of each pixel, which tricks the human eye into believing the virtual illusion. If a HMD (head mounted display) also requires stereo depth information to create depth, the rendering cost is doubled [5]. A way to combat this increased cost is to utilize the foveated rendering techniques, which only properly renders the part of the display that is directly gazed at. Albert *et al* states that there is only as 1.5 degree area in the direct middle of the human sight that is highly visually perceived, called the fovea, while the further out from this 1.5 degree region the visual quality decreases rapidly, especially when in relation to color, defocus, and depth [62]. According to Albert *et al*, outside of a 20 degree arc, visual sensitivity has been reduced by 96%, which means that the remaining 80 degrees of the 100 degrees of field of vision that an HMD allows for currently is more or less squandered visual space [5]. It is possible to use eyetracking, already inbuilt into the Vive Pro Eye, to only fully render the small region of the screen which is in focus of the fovea, while greatly reducing the overall rendering of the outlying region to simulate how the human visual system operates.

The rendering changes happens between eye movements, the so called saccades in which the phenomena of saccadic omission takes place. Albert *et al* states these omissions happens around 50ms before eye movement and normalizes after 100ms which gives a relatively precise timing for the foveated rendering to take place within. Foveated rendering is similar in nature to other virtual reality techniques such as redirected walking [64], where saccadic omission is also utilized, although this thesis will not touch upon this beyond mere mentions in this context, as well as later when discussing movement within a virtual reality environment. To

return to foveated rendering, this thesis only touches upon it since HTC Vive Pro Eye has the hardware to easily perform this type of rendering with minimal work. Otherwise, it is unrelated to the project, beyond ensuring good performance and a lowered computational requirement.

6.3 Recording of eye-tracking data

The eye-tracking data such as pupil dilation, eye fixation points in 3D space, gaze direction vectors are being recorded by using eye-tracking framework script compilation from SRanipal package[84] from HTC. The data will be saved in .txt file as a line of strings, separated with commas for future decomposition using Excel for visualisation of the data. The data will be recorded for each frame to have full information bucket during the experiment. The data won't be written if both eyes won't have pupil diameter and if hardware will lose track of eyes during experiment. This collection allows us to easily gather information about pupil dilation, which can be easily visualized using Excel or similar applications. In addition to psycho-physiological measurements we also include the object name participant is looking at at specific frame to later sort psycho-physiological data by object name looked at.

In addition to eye-tracking data recordings, we are using a replacement for AOI system. Instead of defining AOI or allowing software to generate one using eye-tracking data, we define AOI as 3D that participants are looking at. It allows us to see the dwell time for objects AOI. Both data files of VR-based AOI and eye-tracking data will have timestamps for each data line, which allows us to manually synchronize it will interviews, conducted during the test as part of test procedure.

7 Design

This section will go into the design of the experience. More precisely it will go into the narrative, and how the environment were designed in order to afford the interaction which will be available, and make the environment part of the narrative - using environmental story telling in some shape or form. This section will also present the narrative and its flow. However firstly, we will present the core idea behind the experience.

7.1 Core idea

The game and experiment had to be co-designed around each other, intertwining endlessly, as both story and gameplay had to exist for the nature of relevant data. Since the core idea of the game was to test an actualized narrative with some depth, the story had to be one with a beginning and an end, to create a proper narrative structure.
With the inclusion of the interactive dimension of an interactive narrative, which is as some would argue rather vital, the player would need to have a way to both gain access to the narrative, as well as having the option to delve deeper into it, if they so wish [75], for an example of this, see figure 7.

7.1.1 Balance between art and science

As mentioned in the analysis chapter, subsection on interactive narratives, one could argue that an interactive dimension to any narrative text has one of two reasons for existence, either entertainment or forming an unique narrative. Since the mechanics of this game were not meant to be entertaining it would have to be the other option, that every player could gain as much or as little additional information as they wanted, or perhaps could find, so their own understanding of the narrative would be formed by this information feed. Some players might read all the text in the game to gain a more whole understanding while some might just dash to the very end.
In order to stop players from just running to the end within a few seconds we had to create several barriers, one being the format of the game itself, virtual reality. Within virtual reality, with the way our movement has been set up, the players would be forced to move slower around the house, which was a requirement if we wanted them to explore the narrative texts which were scattered about, which would be harder to slow them down if they did not have the full field of vision which a HMD would grant them, compared to a more common computer screen.

7.2 Story

We want to create a coherent story for the participant to explore. This also makes is possible for us to create sections or events which can create hindsight and/or foresight. This being said, whether or not the participants gets the exact same narrative is redundant. We argue

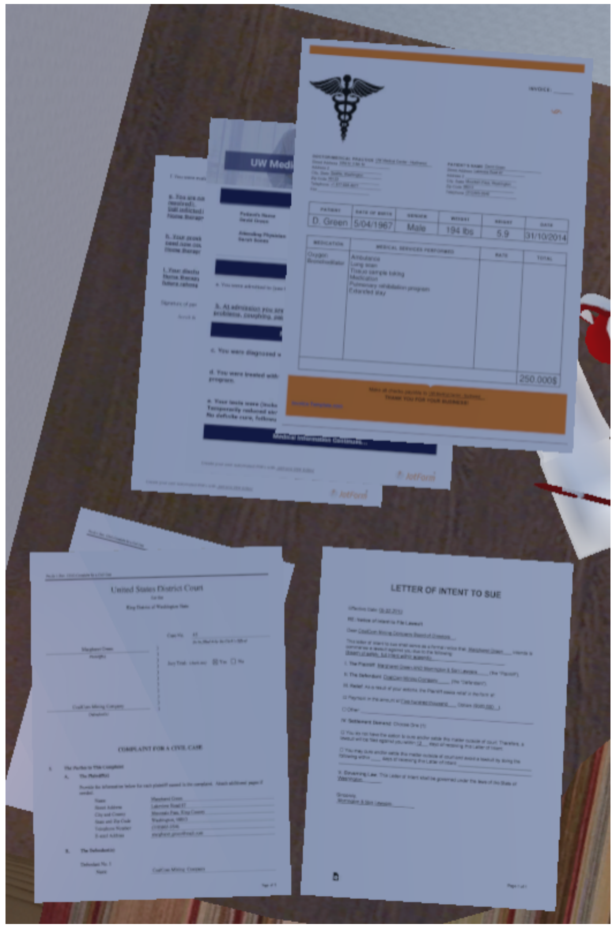

Figure 7: *The players can decide how little or how much they desire*

that even if they create their own narratives during the experience, they will still experience foresight and/or hindsight at certain narrative beats. The narrative we create is going to serve as an underlying logic and help for us as designers and conductors - as well as a guiding factor for the participants.

It involves two characters, Margharet and David Green, wife and husband, who moved out into a lakeside house in the Washington woodlands surrounding Seattle, close to the Olympic National Park.

David Green was a foreman at a local mine, but in 2014 he suffered a grave accident where he was poisoned by gas emitting inside the mine.

He underwent a lengthy, and costly, hospitalization, but there was no cure for him so the hospitalization became home therapy at their quiet house.

Meanwhile Margharet felt vindicated by the mining company who owned the mine, feeling their lack of safety led to the illness of her beloved husband and initiated a lengthy trial against the company.

She became more and more entangled in the legal procedures she did not have time for her husband who was slowly dying, making him realise that his wife was spiralling into a

sorrowful place, fearing what would happen to her when he died, as the mining company was even winning the trial.
With his last energy, before his death, he planned a treasure hunt for his wife, to make her mentally return to a happier time, leading her through the happy beginnings and sad ending of their life together.
The story is experienced through this treasure hunt, as Margharet Green returns to their home after the death of her husband, having been away in the final time both due to court trials but also the final hospitalization and death of David. The game ends with a final note and goodbye from David to Margharet.

The reasoning to why the narrative is as was just told is the basis on which it hinges, the hindsight and foresight investigation. The story constantly goes between past and future, while being rooted in the present, always focusing on creating hindsight and foresight. This is why events mixes together, accident turns into hospitalization which turns into a lawsuit, to finally end up with death. One event comes logically after another which would not be too difficult to understand for a reader, so it is easier to test.

7.3 Narrative flow

While the story is very linear, the way it is presented is in pieces, to be mentally put together within each and every one of the participating players.
The model below shows the expected narrative trajectory, with potential hindsight and foresight which we as designers expected to happen, at least within some players. Not every potential will naturally be fulfilled in every player. See figure 8

What the notes say and why they say what they do will be presented here, with the actual notes in their full length can be found in appendix no. 4.

- Note 1 introduces the story and goal of the game, telling the players to follow a so called treasure hunt by finding more yellow notes.
- Note 2 and 3 leads the players close to important pieces of information, setting up both the accident in the mine as well as a lawsuit.
- Note 4 is where the players find a great amount of pill bottles, telling them somebody is very ill.
- Note 5 is there to let the players read the many surrounding texts, both hospital files as well as get well cards confirming whoever got into an accident was in fact from the mine, and lives in the same house.
- Note 6 is where the tone of the narrative shifts, from just an accidental tragedy in a coal mine, which led to hospitalization and a lawsuit, to something more mournful. The tonal shift is to set up for the later reveal that David is dead.

- Note 7 is just a cute comment.
- Note 8 sets up the reveal, but also states the split between Margharet and David, with the surrounding texts in the bedroom makes it very clear what David suffered from.
- Note 9 is the final note from David, confirming his death.

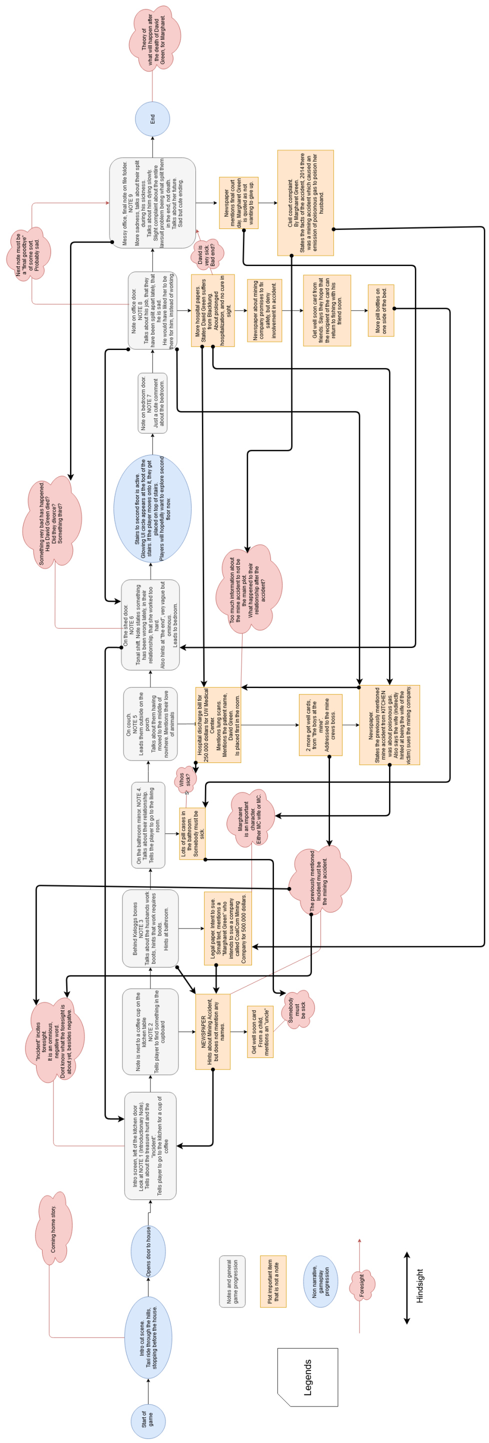

Figure 8: *The narrative trajectory, combined with expected hindsight and foresight. See appendix no. 3 for a larger and more readable version*

Besides the notes the participant can also find legal papers (see appendix no. 5) as well as medical papers (see appendix no. 6), which further explains the story and serves to tell the user that it was the husband who was sick, and the wife who was suing the mining company. This is shown by mentioning them by name on the documents, furthermore we spread out some "get well soon" cards from friends and family (see appendix no. 7), again to help insinuate someone was sick. We also put in some news paper clippings (see appendix no. 8) in the environment which further explains that there is a lawsuit going on. This is also where the user is being told that there was an accident in the mine, and it was due to poisoned gas.

7.4 Mechanics

The core mechanic of the game is utilizing a human sense, vision, to read the visual texts around the house. It could have been made with audio notes, but for two reasons we decided on a written format. See figure 9

Figure 9: *The first group of narrative items the players should find*

The first reasoning is speed of implementation, as it is much simpler to write rather than finding a voice actor, if immersion has to be kept, as a bad voice actor may pull a player out of the experience.
The other reason, much more intricate to our experiment, is the lack of eye tracking for audio, as we would have had to add another biometric to the experiment in order to harvest useful data.
From a purely game design perspective, this also means that each player can go through the text as they see fit, as well as return to it later on, without having to go through pre-ordained audio files in order to find the specific part they wanted to revisit.

7.4.1 Interactions

Mechanical interactions with the game world has been kept to a minimum, so even players who did not have any experience in virtual reality could pick it up and try to complete the game. Door interactions were necessary for the experience of exploring a house, each closed door naturally indicates something hidden, or out of sight, as will be touched upon later within the context of affordances.

Interactions were also useful for picking up the text notes to bring them closer to the display, so the players would not have to bend over in uncomfortable positions. It was either that, or place every note on a wall, in eye height.

Then there is the only game play interaction which blends into the puzzle aspect of the game, the two Kelloggs brand cereal boxes in the kitchen. See figure 10

Figure 10: *Two cereal boxes hiding a yellow note behind them. The boxes are interactable*

In order to reach for the note, the players should be able to move aside the cereal boxes. Of course, this might lead them to believe that everything might be intractable, which they are not for one major reason. The experiment is focused upon the narrative, not the interaction, which just exists to enhance the immersiveness in order to bring the players into the story world. If there had been full interactibility, the play session could just be reduced to a playground, which would give no data for us.

7.4.2 Puzzles

The simple mechanics of the game are leveraged by the game concept being a treasure hunt, albeit a very simple one that is near impossible to fail. Every room has a yellow note, with the kitchen having two as it functions as a tutorial area to get the players accustomed to the flow of the game. Each note has a hint about where to get the next note, even if the hints are actually not where the note exactly is, but rather where the player can spot the note from, if they follow the hint.
One such hint is the one on the couch, leading the players to the porch bench. Once they stand there, the not note on the porch door is easily spotted with its sharp yellow color. A small spot light was also added to several of the notes, such as the porch note, to make it more visible in the environment 4.3.4.1. See figure 11

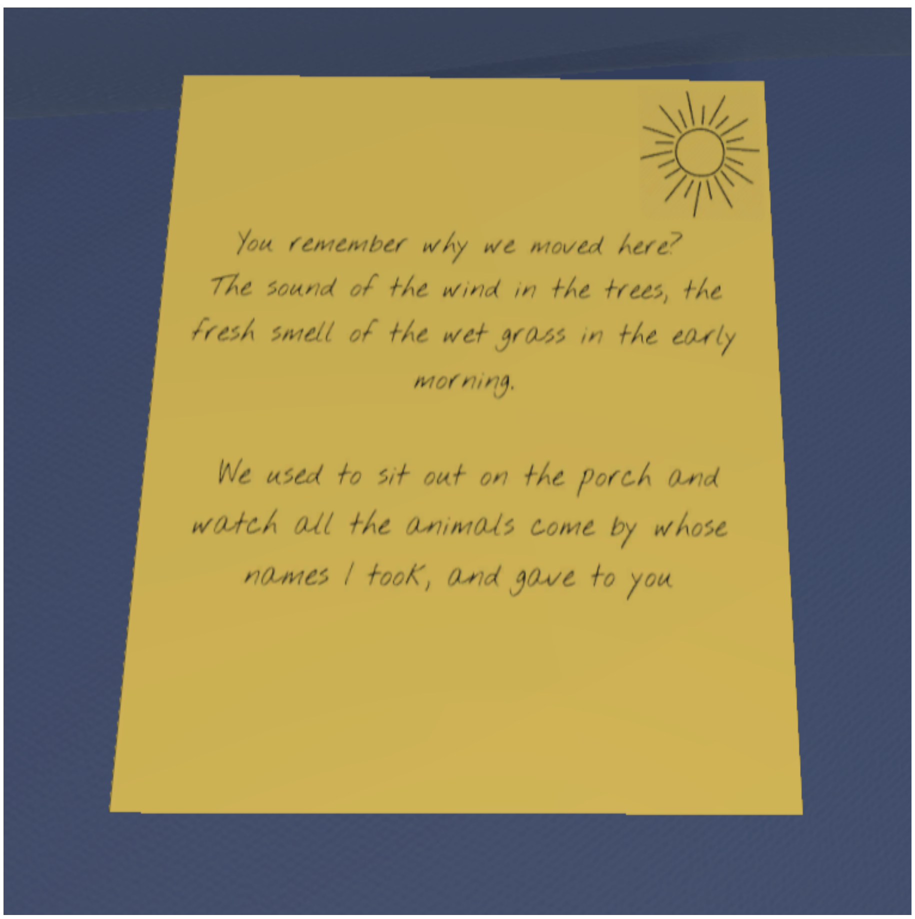

Figure 11: *A hint and explanation of all the nicknames mentioned up to this point*

One could also argue that the format of the experiment was a sort of puzzle, with the players unravelling the mystery live before the test conductors, mentally putting together the different notes into a coherent timeline.

7.5 Setting

The idea of having the player explore a house mimics our wish for the players to explore the narrative, in a slower pace than what most games would, as both eye tracking and EEG would have an easier time picking up any signals if the players were merely doing slow paced tasks. This way any potential spikes would stand out more clearly. Another reason for picking a more "common" setting for a game is the lack of introducing the universe to the player. They might not know who they are or where the house is physically located, but everybody automatically understands what a home is, and which rooms it would normally include, such as a kitchen, bathroom and bedroom. This reduces the experience to just telling the important parts of the story, which becomes a short experience, rather than a bloated one.
Having a short game set in a familiar setting also means players don't have to be confused about anything else than the core narrative, which is what we are investigating. Every player also has a common baseline understanding, which would hopefully reduce personal biases, at least somewhat.
Furthermore we hoped to get the player into the role of the character more easily, if it was a realistic, well understood story, which both returning home and loss of a loved one both are, though the biases of our testers will be mentioned later on.

7.6 Location

The setting of the game is contemporary USA, set around our own time, an unspecified year, placed specifically within the state of Washington. The location of the game is a house perched on the shores of an idyllic lake, within a rural and sparsely populated hillside, surrounded by trees, to create a feeling of both peace and quiet, yet not have the house located within a national park or in a truly remote area, there are neighboring houses whose roofs can be spotted in the distance. See figure 12

The outdoors location are utilized both as backdrop seen through windows, and on a short introductory taxi ride to the house.
The very first time the players are given control over their character, they step outside of the taxi, standing outside with a fine view of the hillside as the taxi drives off.
The second time is when the treasure hunt leads them out onto the porch with a view over the quiet lake.
One could argue the second floor balcony is a third outdoors location, but it has the same view as the porch, albeit with a higher altitude.

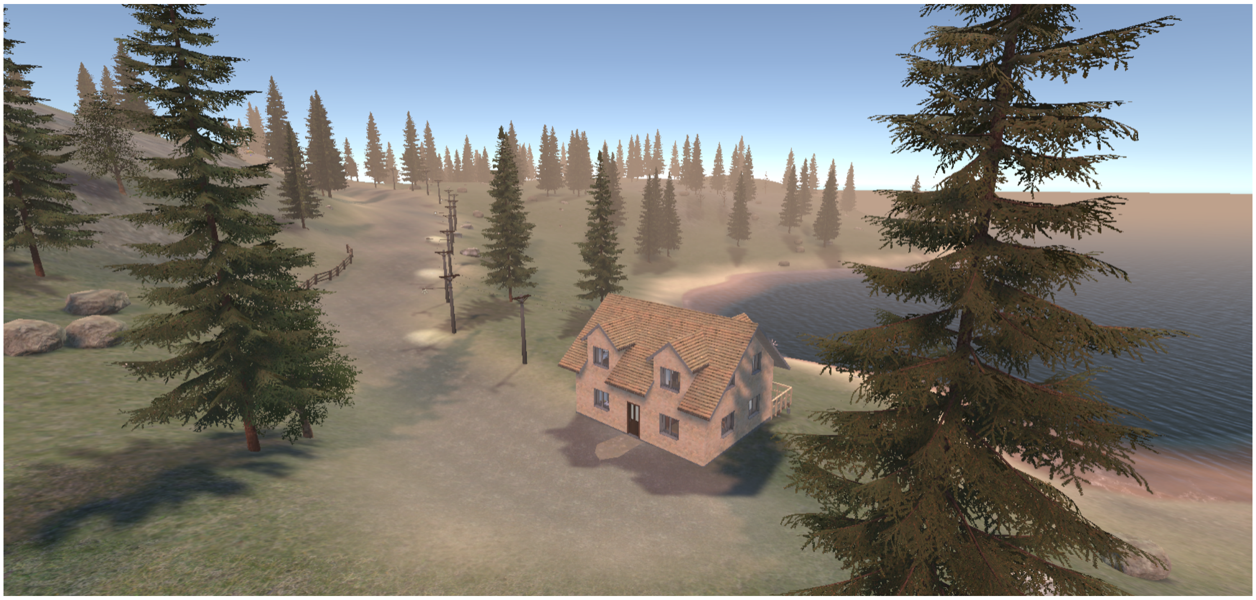

Figure 12: *The lonesome lakeside house*

7.7 Set design and props

For the moodboard, see figure 13. The general design of the houses interior is a mixture of modern materials and old hard wood, to make it look like an elderly couple who has upgraded some of their less traditional furniture, such as electronics, to keep up with the modern age.
Each item had also been selected to make the entire rooms, or to borrow from movie lingo, sets appear lived in. The house should give off an atmosphere of daily life, of nothing extraordinary, to enhance the feeling of the story being tragedy which strikes a normal household. The entire prop list with links and sources can be found in appendix no. 9.

7.8 Layout

Each room has a relatively sparse decorative style, aiming towards the choices a near elderly couple would decide to decorate their home with. It is not too cluttered as it would be both much harder to spot any clues, or single out narrative important items, as well as eye tracking would need to be many times more precise in order to differentiate between a large amount of objects.
The layout of each room tends to follow a very specific pattern, in which the player are invited to walk on an invisible path by following the notes which are laid out before them. This means that the path the players are to follow has been laid out before them, without them knowing it, though they still have the freedom they themselves decide upon. See figure 14 14
Some players went in a direct line for the notes, to then later look at the other notes

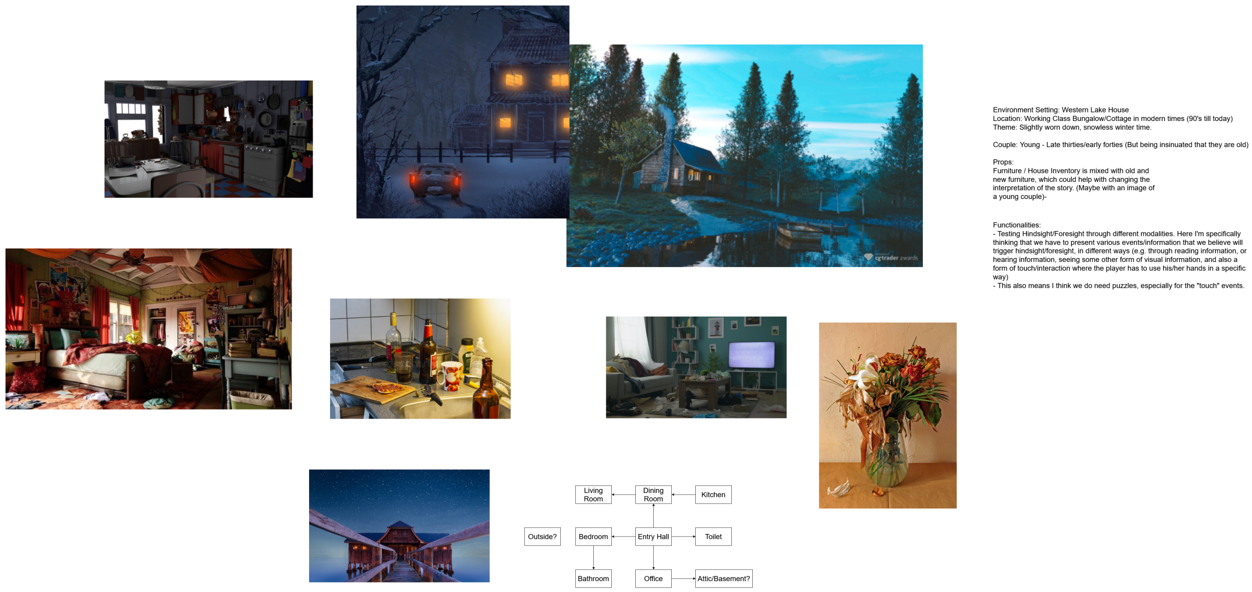

Figure 13: *The final mood board with the current inspiration for the house, though with narrative and level design changes from the current iteration*

without any order, though nobody got stuck in any room, not even the living room which had a different type of door which could have confused less experienced players. See figure 15. These types of pathways were luckily very easy to create as the house was not large enough to facilitate a confusing layout, or rooms which were in the middle of the house. E.g. a study placed within a small maze of rooms, which would require the player to mentally create a complex map of the house layout. See figure 16.

As seen above, when also considering the figures text, there was always one expected path, so to speak. When expected is said, it is not that we as designers believe that every participant will follow this path, but rather that this is how attention has been manipulated, or attempt at manipulation, to create a greater chance of this, so every reader has a chance of following the same narrative trajectory, with the same beats.
One could argue that this exact way of creating a level is detrimental to both the freedom of virtual reality, and interactive mediums as a whole, but as a counter point, it merely facilitates a pathway, not enforces it. It is there to create a natural flow from item to item, to create a natural narrative pace.
It can be seen in the overview of the upper floor, from previously in this chapter, and in a lesser way on the porch. See figure 17. Here the players attention is drawn towards the lake, then to the left, as the right affords no entrance. The porch is similar to a long hallway, which ends with the yellow note as a stark contrast.

Figure 14: *View of the living room, with a line through the image going from the right to left, from orange tinted note to the porch doors*

7.9 Surrounding environments

To empower the underlying feeling of solitude in the game, the surrounding environment had to mimic this narrative dimension.
The woodlands around the house are sparse, but non threatening, as a lonely house in the woods could easily be the setting for many dreadful stories. It was important that it felt natural and realistic, while being neutral enough that the players did not focus too much on this, as computational power would be too high if the environment was as detailed as the house itself.
Next was the quiet lake, giving a feeling of serenity, while it was also a leftover from the previous version of the story, in which a boating accident was the crux the entire story coalesced around.
After the change of story the lake was kept in as a visual backdrop, being the empty, truly lonely vista to enforce the feeling of truly being alone, even if the player does not yet realise that the story is about loss, when they get to stand on the porch and overlook the waters. See figure 18

Figure 15: *The second floor of the house. The pathway is from the middle stairway which ends in the lower room, then to the left bedroom, upwards to end in the right office.*

7.10 Level design

As mentioned before, Oculus Story Studio argues for the lack of any controlled linear narratives [59], our game has a very specific path through the house, though the player does not need to interact with everything to proceed.
What they do need to do is get near each yellow notes in a room before the next door unlocks, though we have tried to hide this by creating a narrative flow which would naturally lead the player from room to room.
It is only if the player tries to sneak around this invisible barrier that they would notice the metaphorical bars which cages them into our predetermined path.
This might be worse for a pure virtual reality experience, but it is far more effective for the experiment as this forces the player to experience the story in a linear manner, which makes it possible to compare each testers foresight and hindsight. Since there is a difference in how

we as designers and the players understands the path through the house, one small pilot test was done, after a lengthy user centric design phase.

Figure 16: *Birds view of the living room. Notice the path from door to orange note, to coffee table and finally to the porch doors.*

The pilot test (*See section 9.1 for test procedure*) made us understand we had to lock the doors. We also got the idea of removing the kitchen door to lure the players into the first room by their own volition. After all, an open door is an invitation, but a lack of a door is an even stronger one. Their gaze will automatically enter the room, and then there is not far from just going in.
Beyond that, the pilot test showed that the basic format of the game, following yellow notes throughout the house in a treasure hunt works very well, even if a player skips a note, though they then lose some of the narrative.

The level design also follows the beats of the story, with the first floor being about what happened while the couple still had hope, with the second floor being about what happened after the two started to split apart due to the court trials and illness. The note on the porch is what separate these two levels, being the springboard between first and second floor, also quite literally as access to the second floor opens after reading this.

7.10.1 Control scheme

Currently there are 3-4 movement types that are being used in games/systems in VR. Although, some are more generic and easy to implement or use, the VR scene tries to implement complex locomotion systems that could benefit from "real" reality. Redirected walking can be named as one of the systems, that benefit from a physical space. It creates an illusion by

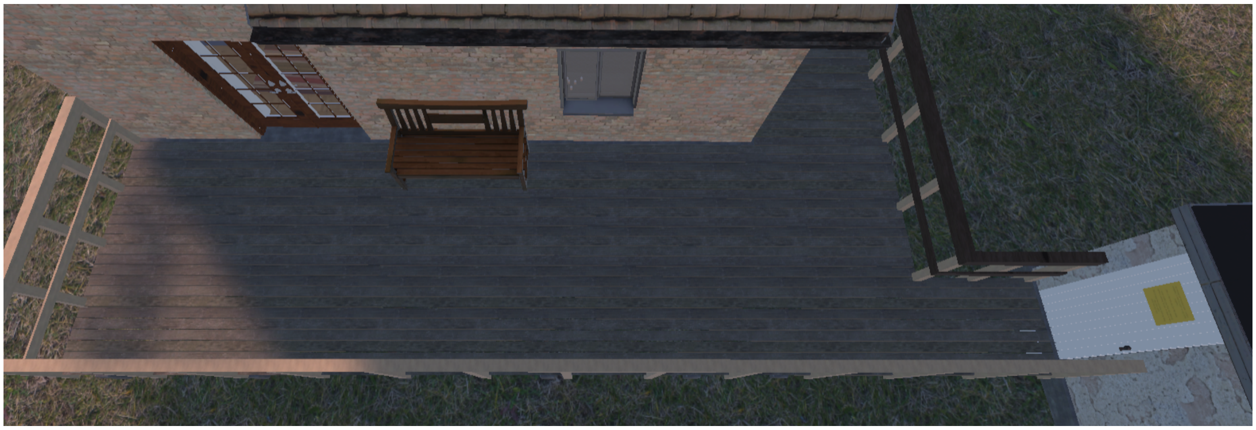

Figure 17: *View of the porch.*

having a person walking in one direction, but VR software will seamlessly rotate the world to utilize the whole space, available for computed reality. In addition to redirected walking, there are lots of other options that emulates real-time walking, which are less immersive and not as attractive as the most common ones such as teleport, dash, etc.

Even though redirected walking seems to be the best option for VR locomotion, it is not widely used in VR environments. Most application or games in mentioned reality are using either teleport, dash, walking or all of them. The main reason why redirected walking is not being used widely is because not all VR system have same system architecture, some VR helmets provide less space for movement till the point where redirected walking cannot be used.

Teleportation is currently the most popular option in VR and also the easiest one to implement. The way it works is quite simple: when player press the teleport button the UI appears by showing in which position the player will be moved after he releases the button. While the person is being moved to the selected position, the environment is fading in and out to eliminate motion sickness while moving from the initial position to the selected one.

Dashing can be named as a younger brother of teleportation as it uses the same mechanics, but moves player by shorter distances and furthermore does not fade when moving player to maintain the coherence of naturalistic movement type. It is a more practical option, as long as the player is not required to move for long distances in a game, and additionally slow downs a game play, which suits an environmental storytelling.

Walking movement option is a tricky one. In HTC Vive, player controls his movements by moving his finger on touchpad and direction of finger movement represent player's movement in VR. It is slowest movement option as it tries to emulate natural speed of walking, but it feels unnatural in the first place.

Figure 18: *Porch view of the house with a neighboring house barely spotted over the hills*

8 Implementation

8.1 Interactions with objects

The players interactions plays an important role in the process of storytelling. The sequence of interactions defines how the player will perceive the narrative provided to him and as a result he will interpret it accordingly to the actions he made during the interactive experience. To enrich the interactive experience several interaction types were implemented.

Firstly, the ”pick up” function was added. Players should be able to pick up specific objects, examine then and throw them away, or put them down again. To implement it, a combination of SteamVR scripts were used. Each object, which was classified as ”Interactive”, would have a Rigidbody added to it to simulate real-time physics. Additionally, two SteamVR scripts - ”Intractable” and ”Throwable” were added as well. Intractable script would control all interactions that took place when a player picks up the item, including physics, animations and other sequences. The ”Throwable” script would control velocity and other physics parameters when the object is being thrown or released. In addition to this, components of each object were given a collider which allows scripts to execute physics-based task sequences. This combination allows for picking up objects, rotation as children objects of the Player object, move it in 3D space and if needed, to throw it or let it go at specific location in a scene. This interactions are being used for sticky notes, that are being used as main storytelling objects as well as to some additional storytelling elements and some random items as cornflakes packages, etc.

As the level has several rooms, interactions with doors/closets/shelves were introduced as part of the interactive real-time experience. Each door would have several colliders to achieve a naturalistic door behaviour. To open the door, the parent door object would already have introduced an ”Interactable” script for interaction purposes as well as ”Circular Drive” script. A second script allows the door object to rotate around its root position. To enable this interaction, the player needs to target a collider with his controller, placed on the door handle, as the rest of door is being ignored by the controllers hovering Also, the ”Circular Drive” script allowed for limitations on how far players can rotate the doors based on the initial door position. Before the final experiment, we had several others interaction types such as Linear drive for closets, but it was discarded as the experiment was aiming to test changes in hindsight and foresight of a person, not to test interactions types.

8.2 Movement in virtual reality

For this aspect of the interactive experience the teleport version of movement is being used mostly because the player should be able to move from ground floor to the first floor bypassing the stairs. If the interactive experience would be implemented using only one floor, the dash movement type would be used in its stead.

The implementation of teleport was done mostly by utilizing the SteamVR pre-existing ”Teleport” script. It works by combination of ”Teleport Area” scripts attached to objects.

The ways the teleport scripts logic works is tricky in a way - the level is being populated with duplicates of objects the player may want to teleport to. Then, the duplicates of these objects are moved a little bit higher on the "Y" axis on the 3D space and afterwards the "Teleport Area" script is being added to the object with a box collider. Then the "Teleport" prefab with the "Teleport" script on top of it is placed in an active scene or one of the scenes to initialize the teleport functionality and cover all processes such as raycasting to the 3D objects, defining if the user can teleport on top of it by using color indications (red - teleport is not allowed, green - teleport is allowed) and move the player onto the raycasted position if the raycast hits objects with "Teleport Area" or "Teleport Point" as attached scripts. To

eliminate any possibilities of teleportation through walls, ceilings and some floor objects were modified with additional colliders to stop the raycast from going through the game object.

8.3 Lock/Open door,enable teleport area systems

As the main area of the thesis is the narrative understanding, the team decided to limit the players movement area depending on the stage of narrative trajectory. This means that the player should not be able to enter a specific rooms before it is needed for the narrative to progress.

To ensure this linear narrative progression, it was decided to implement a room unlock system depending on which sticky note has been seen or picked up. The system contains several box colliders which have only one task in the level - to be the trigger for specific a door to be intractable. The trigger colliders are being placed nearby sticky notes that are pointing player to specific part of the level as part of narrative progression. The script "EnableDoor", which is attached to the object with a trigger collider, will have a reference to the door which needs to be intractable if the is a collision triggered by the player. The doors "Interactable" is the component that is being enabled during the collision with player. This system, as was mentioned before, allows for a linear narrative progression which also allows the team to use eye-tracking data with far greater ease, collected during the interactive experience, as all players were experiencing the same linear narrative with the same affordances, in the same order. To further ensure the linear narrative progression, the enable teleport area system

was developed. As the beggining of the interactive experience is taking place on the ground floor, the player should not be allowed to move to the first floor before they are led there by one of the sticky notes. To achieve this, the "EnableTeleportArea" script was written and attached to the trigger box collider near note 6. The script has most of the teleport objects of the second floor as references. Mentioned teleport objects are disabled in the scene by default and are only enabled when the player has collision with the aforementioned trigger collider to allow player to progress.

8.4 Player position tracker

As part of the data gathering process, the team decided to have some type of player position tracker which would allow us to replicate player's position during the playthrough. In the end we implemented two different versions of player position systems. The first one creates a text file with the player's x,y and z position and would record these positions each x frame, where x is an integer, that can be changed by the team. Later this file would be provided to a Matlab script as an variable and as a result the heatmaps of the player would be provided for analysis. In addition to the text-based player position recordings, the animation-based system was implemented to record the point of view of the players. "RecordTransformHierarchy.cs" script would take an empty animation clip and on each late update (update being when all physics/scripts were executed) would take a snapshot of the point of view. When the test ended, the combination of snapshot got compiled into an animation clip. This system, with the addition of the text-based player position system, allowed us to store the full experience and allowed us to recreate the whole experience with a combination of interviews.

8.5 Eye-tracking data systems

The HTC Vive Eye virtual reality headset had in-built eye-tracking hardware, provided by Tobii, we explored two different API's for eye-tracking data gathering. One of these systems is Vive's SRanipal API and the other is Tobii's XR API. For this particular project Vive's SRanipal API was selected and slightly modified to provide real-time eye-tracking data such as pupil dilatation, gazing direction, object distinction etc.

To enable the real-time data gathering process, the prefabs from SRanipal Unity's package were used and placed into one of the scenes to enable simple data gathering as well as enable several debug functionalities such as visible raycasting, which is how gazing is being registered, or recorded, using the mentioned API. As the experiment needed to record the objects each player looks at to define if any new information is changing the users hindsight or foresight, the additional sub-systems were added from the APIs example scenes. Additional scripts would introduce the meaning of "Focus" with an addition to gazing. The "Focus" part of the eye-tracking system would provide such data as which objects a player is focused on, pupil dilatation, etc. For these system to work, the enable file needed to be written, which would define which data will be written to the log file and when user's gazing would be identified as focused. The example script from example project was taken and examined, to see if the evaluation of "focused" gazing is the same as the target implementation of interactive experience requires. After that, the base script with evaluation scripts were re-written to fit our write-to-log concept of eye-tracking data gathering. As mentioned, the API would generate more than 2 data enquires each frame for left, right and combined eyes, and even more for sub-groups of eyes. The script limits data enquires to 1 log per frame, and takes only combined data from both eyes to register mean values for a specific frame. Also, to avoid logging objects that are not important to the test, the script ignores several layers, that are being defined in Unity such as "Ignore Raycasting", "FX", etc. The example of result files of logging eye-tracking data is shown on Figure 19.

Time	3D point.x	3D point.y	3D point.z	normal.x	normal.y	normal.z	Object	gaze direction .x	gaze direction .y	gaze direction .z	gaze origin.x	gaze origin.y	gaze origin.z	left pupil	right pupil
0.02	(156.6	36.5	-47.4)	(-0.1	1	-0.2)	Terrain_0_0-2020071	(0.0	-0.1	1.0)	(8.6	4.1	-39.1)	4.210083	4.479446
0.04	(158.5	37.4	-44.9)	(-0.1	1	-0.2)	Terrain_0_0-2020071	(0.0	-0.1	1.0)	(12.6	3.9	-39.1)	4.29068	4.754669
0.14	(158.6	37.3	-45.3)	(-0.1	1	-0.2)	Terrain_0_0-2020071	(0.0	-0.1	1.0)	(-19.4	5.5	-39.3)	4.494064	4.610229
0.24	(155.9	34.4	-67.2)	(0.9	0	0.3)	Terrain_0_0-2020071	(0.0	-0.2	1.0)	(-30.7	5.7	-39.8)	4.173584	4.441544
0.322768	(156.4	30.5	-69.8)	(0.0	1	-0.2)	Terrain_0_0-2020071	(0.0	-0.2	1.0)	(7.4	3.6	-39.4)	4.03241	4.33139
0.349708	(156.6	31.1	-67.3)	(0.0	1	-0.2)	Terrain_0_0-2020071	(0.0	-0.2	1.0)	(13.2	3.3	-39.3)	4.024918	4.152374
0.377933	(156.8	31.5	-65.2)	(0.0	1	-0.2)	Terrain_0_0-2020071	(0.0	-0.2	1.0)	(9.7	3.6	-39.4)	3.987732	4.246933
0.477933	(157.7	36.7	-47.2)	(-0.1	1	-0.2)	Terrain_0_0-2020071	(-0.1	-0.3	0.9)	(-0.2	3.3	-40.2)	3.713608	4.170776
0.510896	(157.7	37.1	-45.5)	(-0.1	1	-0.2)	Terrain_0_0-2020071	(-0.1	-0.3	0.9)	(-0.2	3.3	-40.0)	3.768433	4.095383
0.533895	(157.6	37.1	-45.8)	(-0.1	1	-0.2)	Terrain_0_0-2020071	(-0.1	-0.3	1.0)	(-29.7	4.9	-40.5)	3.804169	4.203873
0.557172	(157.5	37.1	-45.7)	(-0.1	1	-0.2)	Terrain_0_0-2020071	(-0.1	-0.3	1.0)	(-28.6	5	-40.9)	3.72348	4.068253
0.574139	(157.5	37.2	-45.3)	(-0.1	1	-0.2)	Terrain_0_0-2020071	(-0.1	-0.3	1.0)	(-13.8	4.3	-40.4)	3.849106	4.229904
0.59482	(157.4	37.1	-45.3)	(-0.1	1	-0.2)	Terrain_0_0-2020071	(-0.1	-0.2	1.0)	(-9.0	4.1	-40.0)	3.702789	4.101761
0.612151	(157.4	37.1	-45.3)	(-0.1	1	-0.2)	Terrain_0_0-2020071	(-0.1	-0.2	1.0)	(-20.4	4.9	-40.0)	3.807205	4.249649
0.635098	(157.3	37.2	-45.2)	(-0.1	1	-0.2)	Terrain_0_0-2020071	(-0.1	-0.2	1.0)	(-21.3	4.9	-39.8)	3.823273	4.181366
0.65722	(157.6	38.6	-43.4)	(-0.1	0.1	1.0)	CrownVic.Body.004 (	(-0.1	-0.3	1.0)	(-15.7	4.4	-40.2)	3.888245	4.142593
0.685872	(157.5	38.6	-43.4)	(-0.1	0.1	1.0)	CrownVic.Body.004 (	(-0.1	-0.2	1.0)	(-19.6	4.8	-39.9)	3.728271	4.138321
0.703845	(157.4	38.5	-43.4)	(-0.1	0.1	1.0)	CrownVic.Body.004 (	(-0.1	-0.2	1.0)	(-20.3	5.1	-40.1)	3.876816	3.969421

Object focus data:	Object Name	Time looked at object
17.5293	Terrain_0_0-20200716 - 154804	17.3180
17.9282	Terrain_0_0-20200716 - 154804	0.269593
19.21709	Door	0.461193
19.76141	PavingByFrontDoor	0.497256
21.35579	CrownVic.Body.004 (1)	1.56155
23.99051	PavingByFrontDoor	2.24256
24.75517	Terrain_0_0-20200716 - 154804	0.631386
25.29985	Door_Sheet001	0.352911
39.59337	Terrain_0_0-20200716 - 154804	13.3092
40.12952	PavingByFrontDoor	0.515068
40.66021	TeleportArea	0.406353
41.47381	TeleportArea	0.355318
41.91183	TeleportArea	0.402997
42.52699	Terrain_0_0-20200716 - 154804	0.342758
43.25132	Terrain_0_0-20200716 - 154804	0.606288
43.59098	PavingByFrontDoor	0.305443
44.02276	Terrain_0_0-20200716 - 154804	0.436793
44.45121	Door	0.395424
47.24885	Terrain_0_0-20200716 - 154804	1.702
47.64745	Part [386032]	0.251847
49.75621	Terrain_0_0-20200716 - 154804	1.55021
50.49844	Door	0.474328

Figure 19: *Raw output data from data collection scripts.*

9 Evaluation

9.1 Usability test

Before conducting the final test, all components such as; scripts, level design, performance and test procedure needed to be tested. For this test we asked a fellow Aalborg University student, selected by convenience sampling, to test the interactive experience while providing verbal real-time feedback on performance, level design and overall experience. In general we also made observations on the performance of the program and the general level design.

9.1.1 Test goals

- Find experience altering bugs, such as not being able to pick up certain items or items not being available.
- Find game crashing bugs
- Test if test participants understand the notes and papers
- Test if participants are able to follow the notes without problems
- Find design errors which can be fixed before the final test
- See if the experience runs at the needed frame rate, and does not induce cyber-sickness.

9.1.2 Test description

The test was made to be as much like the final test as possible, with measurements taken. However the interview was not tested here, while we choose to focus on the technicalities of the test. These notes however were taken with pen and paper in danish. Again we were mostly looking for technical errors which could hinder the final test. This test would therefore be categorized as "Quick and Dirty".

We had the participant go through the experience after an introduction to the controls and a general introduction to the experience - where we excluded information about the narrative (The test protocol can be found in appendix no. 10). Afterwards we had a small interview were we went over the notes taken during the experience in order to confirm them.

9.1.2.1 Equipment list

- Noteblock and a pen
- Computer containing the prototype
- HTC VIVE PRO EYE set containing

  - Headset
  - Two controllers
  - Two Base Stations (also known as light houses)
- Two tripods/camera stands for the HTC VIVE Base Stations

9.1.2.2 Procedure

The participant had comment explained the overall purpose of the test and the controls for the experience. Then he was told to just go through the experience while we took notes on how he moved through the house and how he interacted with the objects. After the participant finished the experience we went through the notes and the overall experience from the pilot test. (See appendix no. 11 for notes from the test and voice recordings)

9.1.3 Results

The participant went through the house mostly without problems, however they did so not in the intended order which lead to a lot of confusion as to what they were supposed to be doing. They tried following the hints within the notes but they would lead them back to where they had already been, making them reread notes several times. This means that the usability test provided set of level design changes that would help to easily navigate player through linear interactive experience. The door lock/unlock system was introduced after conducting the pre-test as precaution for player to follow planned narrative flow without jumping from beginning of the narrative to the end without unfolding the whole narrative. In general the traversal of the level was limited in order for participants to get the story in the intended order.

9.1.3.1 Key findings

Again the test was done "quick and dirty", so in general we found some minor bugs which were fixed almost immediately after. However some major changes also had to be implemented, and they are all listed below.

- The first note should be placed a more obvious place, as it was missed immediately, and the participant. We made the main entrance door open to the right instead, which blocks the door to the living room and makes them open the door so the note is one of the first things visible.
- We took out the door to the kitchen, in order to make it more clear where they should go after the first note - as the note mentions the kitchen. This was also done to not encourage them to try and open the other doors in the hallway.
- We introduced a locked door system, where the door to the living room and bathroom would be "locked" until they have been by the note leading to those rooms. The same

was done to the second floor - so that participants cannot enter before they have been on the porch.

- Minor bug fixes to objects disappearing through colliders in the environment.

9.1.3.2 Disclaimer

Before we move on to the final test description, it should be mentioned that we did do another pilot test, which is also considered participant no. 1. The test however worked without major problems so the data collected from that participant is still used in the final test. The only thing changed after this test was that a reset function was created in case any of the notes or objects would disappear out of bounds if they were dropped or thrown in the experience. It simply makes it possible for the test conductor to push a bottom on the keyboard while the experience is running, which then returns a note to its starting position - this can either be done for the individual notes, all the notes or all objects.

9.2 Final test

For the final test, as was mentioned in experimental design section, the main interest, was to register any psycho-physiological markers that could hit hindsight/foresight usage or changes with them. In addition to eye-tracking as collector of real-time eye data such as pupil dilatation, focus objects and gazing, the real-time interview were conducted to follow real-time changes in person's hindsight and foresight.

9.2.1 Test goals

- See if there is an increase in pupil dilation which could be connected to cognitive overload - which suggests something is being stored in their memory after reading the final note in particular
- Correlate the data collected from the eye tracker with the interviews to find sections of interest in the experience, then see if there is anything indicating hindsight/foresight in the eye tracking data.
- Find a significant difference between data when we believe they are experiencing foresight/hindsight, to when we believe they are not.

9.2.2 Key findings

9.2.3 Sampling method

For this test the convenience sampling was used and test participants were mostly students affiliated with Aalborg university branch in Copenhagen or friends of the conductors. Initially it was planned to have more than 15 participants for testing to have trustworthy data but due to the COVID-19 outbreak the number of participants was decreased to 10.

9.2.4 Data collection

After test participant is being introduced to experiment and flow of experiment and the hardware has been put on participant, we are starting the interactive experience from Unity. From the first milliseconds of interactive experience the eye-tracking data is being registered and marked by having local game time timestamps for further synchronization with interviews.

We also stopped the participants after they have looked through a room, to ask them two to three questions - We wanted to know their immediate impression of what the story was, and if anything changed from last time they were asked, and what they think will happen next. This was done in order to understand their thought process as they went through the narrative - as to find sections which were more interesting in terms of if we can see anything on the eye tracking data. We chose to interrupt them as they were playing, while we did not want hindsight bias to occur (*See section* 4.1.1.1), making them explain to us how they interpreted the story as they were experiencing it. We also ended the experience with two final questions; the first one where they would recap the story or as they interpreted it at the end, and if they could remember any point during the experience or a significant item/items which made them change their interpretation of the narrative.

9.2.5 Test setup

For this experiment we were located at Aalborg university Copenhagen, in building B located at Frederikskaj 12, 1st floor in the Augmented cognition lab. This was also where we got access to the equipment for the prototype and the experiment. There were two test conductors present at the test. One was in charge of the procedure; meaning they would introduce the experience and the controls, as well as being the interviewer. They could also help if anything went wrong with the equipment (I.e. A participant would get tangled in the cord to the VR headset), or if the participant felt sick during the VR experience. The other test conductor was in charge of writing notes during the experience. It was noted down if an unforeseen bug occurred, when they spoke out loud, and when they answered the questions during the interview. Notes taken can be seen in appendix no. 11. The second test conductor was also in charge of starting and ending the voice recordings, these can be found in appendix no. 11.

9.2.6 Equipment list

- HTC Vive Pro Eye headset
- Two HTC Vive Pro controllers
- Two HTC Base Stations
- Two tripods
- One phone for audio recordings

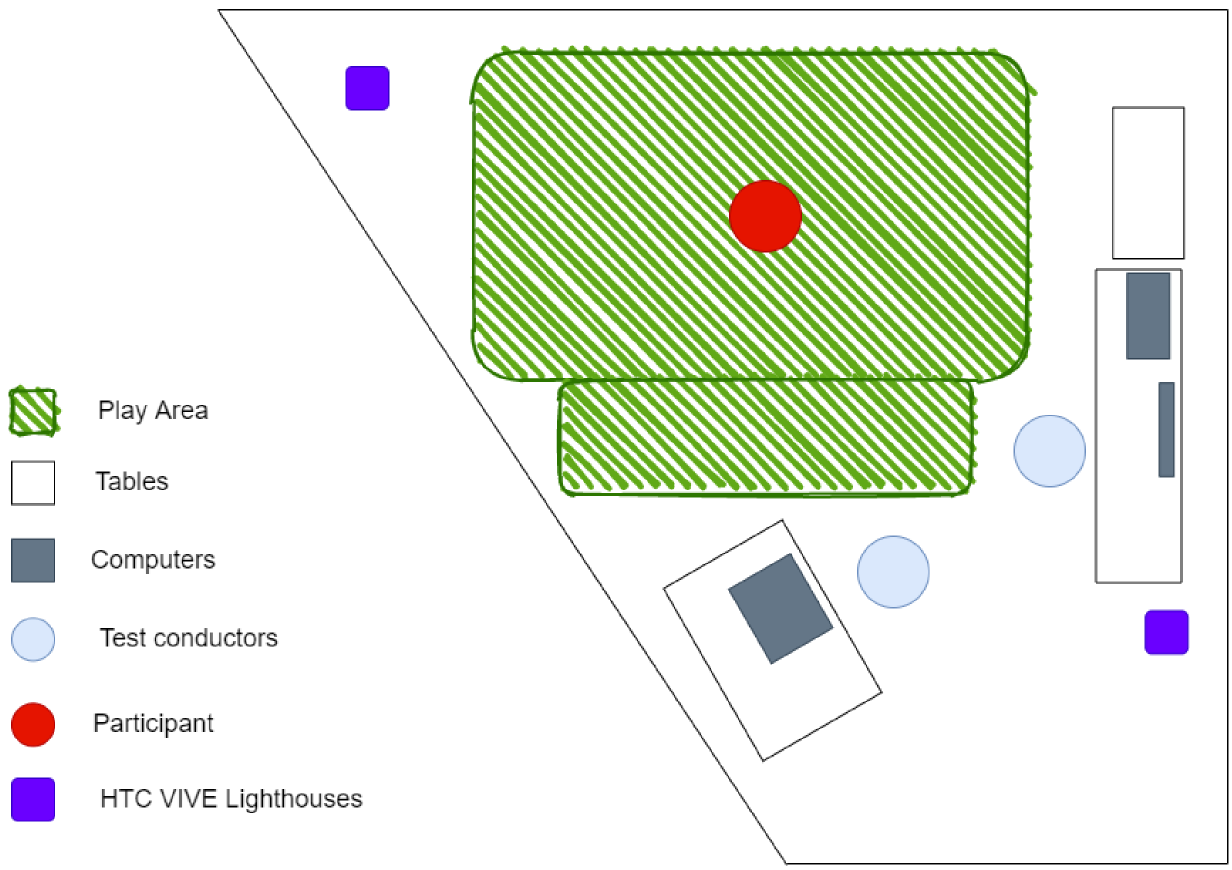

Figure 20: *Test setup showing the play area, participant, and test conductors*

- One computer to run the experiment on
- One computer on which to take notes

9.2.7 Test description and procedure

Every test was done according to the exact same procedure, which was as following (The procedure can also be seen in 21.)

- Welcoming the participants.
- Going through the test protocol (see appendix no. 10).
- The control scheme is explained.
- Each participant signs the consent form (see appendix no. 12).
- Help the participants to equip the equipment.

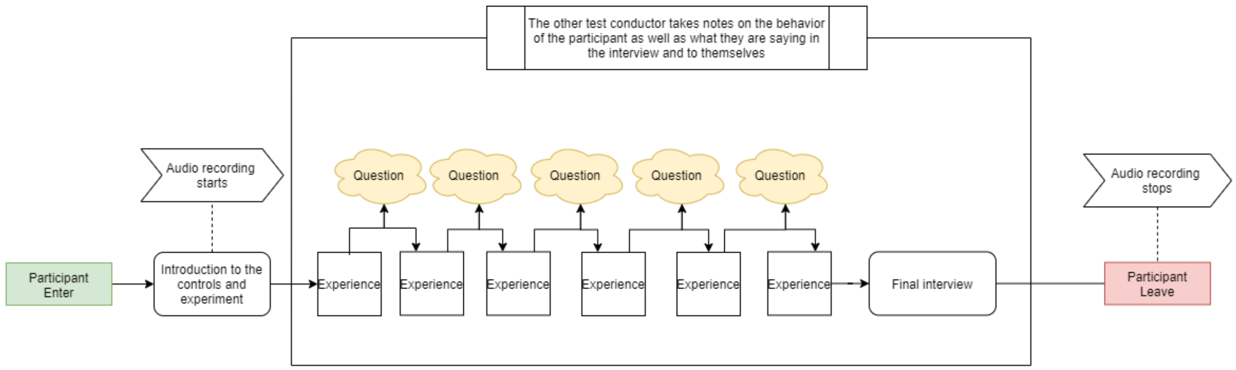

Figure 21: *A flowchart showing the procedure of the test*

- Start audio recording.
- Let the participants play till after note 1.
- Stop the participant and ask them some questions.
- Let the participants play till after note 3...
- *The loop between letting the participants play until after the next numbered note, ie. note 4, 5, 6, 7, 8, 9 and then stop them to ask them some questions until the end of the experience, which is note 9*
- Tell the participants they have reached the end, tell them they can keep playing until they desire.
- Help the participants out of the equipment.
- Perform a final interview.
- Thank the participants for their assistance.

The questions asked during the interview were:

- What do you think the story is now?
- What do you think will happen next?

The final questions were:

- Retell the whole story.
- Were there any notes which were more important to the story than others? I.e. What were the most important notes/items.

9.3 Data Analysis

The following section describes our method for processing the collected empirical data. This involves, but is not limited to, cleaning, transformation, removal of outliers, baseline correction and plotting.

9.3.1 Interviews

As described in the final test setup (see section 9 and fig. 21), we stopped the participants recurrently, immediately preceeding their exit of each room, and asked them about their impressions of the narrative at each given point. We likewise asked them to recap their experience of the narrative, at the end of the experiment, after they returned from the virtual reality of the experiment, as well as at which points in the narrative they felt their impression of the story changed. The results of these small interviews, were then used to specify elements from the narrative, which (fairly) consistently across participants where described as having an impact to their perception of the story. By this, we extracted that the following notes were an area of interest:

- Note 6: Porch note on shed
- Note 9: Final note in office

"Note 9" was regarded, as per design, the narrative element which for most, produced a change in the participants' interpretation of the narrative (8/10). This result was used to inform our further exploration of the empirical data, as we could then define a temporal window from which to extract the physiological measurements, e.g. the pupil dilation. The full notes taken during the interviews can be seen in appendix no. 11, condensed notes can be found in appendix no. 13, and voice recordings for each participant can be found in appendix no. 11.

9.3.2 Eye-tracking

The following section describes our process for evaluating the data recorded with the eye-tracker.

9.3.3 Cleaning policies

After the recording of the real-time eye-data during the experiment, the data needed to be cleaned for corrupted/missing data. For this we decided to remove distorted data-points (often the result of blinks or reflections in participants wearing glasses), as the frequency of the data was high enough, and the risk of missing data was equal for each participant and throughout each trial, as to not affect the overall results [55]. However, for the baseline, it was decided that any missing data within the chosen period for the baseline, was to be interpolated. This was only needed for participant no. 3. In one trial (participant no. 10), the right eye was never registered throughout the experiment, and as such only the left eye was interpreted. However, as both baseline and data was extracted from this remaining eye, the proportional change in pupil size should not be affected much compared to the other participants, from which both baseline and data was extracted as a mean of both eyes.

9.3.4 Filtering

As previously described (see section 9.3.1), the temporal window which we chose to examine, was that of "Note 9". Hence, the data was filtered, so data not affiliated with this specific narrative object were excluded for the further analysis (albeit datapoints in close proximity to the desired object, were used for extracting the baseline (see section 9.3.5).

9.3.5 Baseline

In order to account for both the varying pupil size from participant to participant, as well as random fluctuations in each pupil during the experiment[42], we performed a baseline-correction in the form of baseline-subtraction for each participant during the temporal window of interest. The subtractive baseline-correction has been argued to improve statistical power, and be less sensitive to "noise" in the dataset compared to divisive baseline-correction[55]. As the pupil's response to stimuli is described as happening after approx. ± 220 ms[55], the baseline was extracted for each participant as the mean of the observations for both eyes, within ± 220 ms of the start of the temporal window of interest (e.g. the baseline for "Note 9" was extracted ± 220 ms within the start of their reading of the note). This duration of the baseline period was preferred over a longer baseline period, which can be "susceptible to pupil-size fluctuations during the baseline period"[55, p.98]. The baseline was thus extracted from between 15 and 20 observations for each participant. This baseline was chosen, as it was decided that a baseline *just* before the onset of the cognitive processes expected to happen during the reading of "Note 9", would minimize that the baseline was affected by such cognitive processes. Furthermore, this baseline would minimize the effect a potential change in luminance at the current point in the virtual environment could have on the pupils, compared to taking a baseline from another point in the experiment, e.g. upon entering the narrative.

9.3.6 Removal of outliers

To account for potential distortion of the data by unrealistically small (and in theory also large) pupil size registrations, e.g. due to data loss or other distortions, the data was purged for outliers (see section 9.3.3). After the baseline-subtraction, we examined the distribution of the data within the temporal window of interest, by plotting the data for each participant on a histogram (see example in fig. 22, and the data for all participants in appendix no. 14). The data was plotted after transforming the data using the inverse hyperbolic sine function (asinh) to enhance the output as to more clearly visually "gaps" in the data. Since the data was plotted *after* baseline correction, asinh was used instead of the more common logarithmic transformation (log). With the histogram, we were able to visually analyse the output and

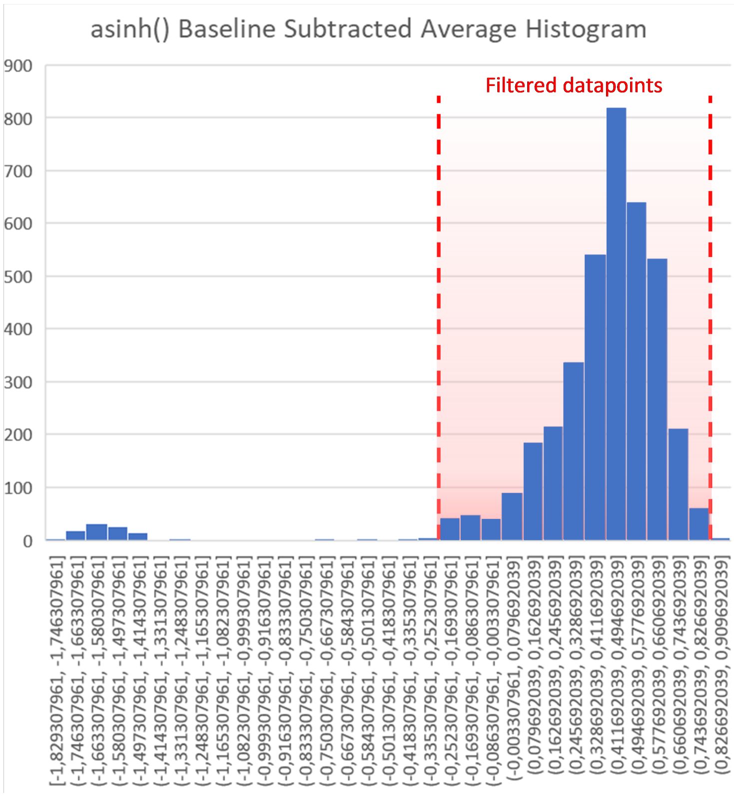

Figure 22: *Example of plotted histogram of averaged pupil dilation datapoints transformed by asinh()*

the ”gaps” in the data. By this, we then chose an appropriate cut-off point individually for each participant to exclude these outliers, as they represented extremely short durations of pupil dilation, and could therefore be regarded as noise in the data.

9.3.7 Plotting and comparing

For each participant, the final dataset (after cleaning, baseline-subtraction and removal of outliers) was plotted in a line-diagram showing the proportional change in pupil dilation in relation to each participant's baseline value, for the course of their reading of ”Note 9”. As pupil dilation data is always noisy (even after the previous steps)[55], a linear trendline was added to each graph, in order to visualize the general tendency in pupil dilation across the time of reading ”Note 9”, thus seeking to exclude the ”noise” still evident in the data. From this trendline we extracted the difference in score-value (the change in percentage points) between the beginning of their reading of ”Note 9”, and the end of reading. As such, the final results of this, shows the amount of increase or decrease in pupil size, proportional to the baseline, over the course of the participants' reading of ”Note 9” (e.g. a trendline starting at 10% below the baseline, and ending at 5% below baseline, shows a final result of a 5% *increase* in pupil size compared to the baseline, over the course of reading ”Note 9”).

9.4 Test results

After clearing the data and analyzing the diagrams of pupil dilation progression for each participant (see Appendix no. 14), the mean values of pupil dilation for each participant were extracted while they're looking at particular story related objects 23. Main idea of having such a data to see a trend or if there are any story related object that will have high overall pupil dilation value. Full values are included in appendix no. 14.

Note 1	Note 2	Note 3	Note 4	Note 5	Note 6	Note 7	Note 8	Note 9
3.807	3.608	3.856	3.839	3.001	4.159	N/A	3.539	4.280
4.085	3.999	4.171	4.190	3.526	3.827	3.841	3.655	3.635
3.194	3.126	3.102	3.250	2.757	2.952	2.979	2.866	3.060
3.292	3.168	3.394	3.246	2.614	N/A	3.143	2.999	3.094
4.027	3.691	3.895	4.004	3.461	4.190	3.870	3.609	3.984
3.713	3.634	3.903	3.931	3.110	3.885	3.646	3.584	3.696
4.612	4.038	4.782	4.566	3.381	3.356	N/A	4.267	3.170
4.051	3.968	4.075	4.233	3.517	3.452	3.384	3.816	4.193
4.110	3.851	4.040	3.993	3.165	N/A	N/A	4.162	3.926
N/A	3.729	3.529	3.877	3.219	N/A	N/A	3.554	3.878

Figure 23: *Mean values of pupil diameter while looking at primary narrative objects (Note 1 - 9).*

As previously described, after going through the interviews, we identified that the main area of interest for further in-depth analysis is the "Note 9" narrative object. After calculating a baseline for each participant for "Note 9" (see section 9.3.5) and cleaning this specific part of the dataset to remove outliers, the baseline for each participant was compared with the mean value of the pupil dilation while looking at "Note 9". For comparing the significance of this comparison, we ran a repeated measures t-test to identify if there was any statistically significant difference between the two conditions. The t-test suggested no significant difference between the two conditions resulting in $p=0.400$ for one-tailed and $P=0.801$ for two-tailed t-test (see fig. 24).

Next, to indicate if there was an overall rise in pupil dilation over the course of the reading of "Note 9", we examined the trendlines which were plotted for each participant. The trendlines showed a rise for 8 out of 9 participants (participant no. 1 was excluded as there was no data for Note 9). An example of one such plot with trendline is showed in fig. 25. The initial and the final value of the trendline for each participants were compared as two arrays and analyzed by running a repeated measures t-test. This test showed a statistically significant difference with $p=0.0045$ for one-tail and $p=0.009$ for two-tailed t-test (see fig.

SUMMARY			Alpha	0.05		Hyp Mean	0	
Groups	*Count*	*Mean*	*Std Dev*	*Std Err*	*t*	*df*	*Cohen d*	*Effect r*
Baseline	9	3.649899	0.391366					
Note9 AVG	9	3.621474	0.43009					
Difference	9	0.028425	0.328579	0.109526	0.259528	8	0.086509	0.091373
T TEST								
	p-value	*t-crit*	*lower*	*upper*	*sig*			
One Tail	0.400890871	1.859548			no			
Two Tail	0.801781742	2.306004	-0.22414	0.280993	no			

Figure 24: *Repeated measures T-test results for baseline and mean values for Note 9).*

26). As such, we find that there is indications that the null-hypothesis might be disproved, however the results are not decisive as to the cause of the increase.

Following this, we examined if there was a correlation between the pupil dilation while reading "Note 9", and the amount of time each participant spent fixating on the story items, as a greater time spent on the story items might suggest a better understanding of the story, and thus potentially result in less rise in pupil dilation during the reading of "Note 9". This comparison showed that there was no apparent correlation between the pupil dilation and the amount of time spent reading "Note 9", compared to the overall game time. For raw data and t-test see appendix no. 15.

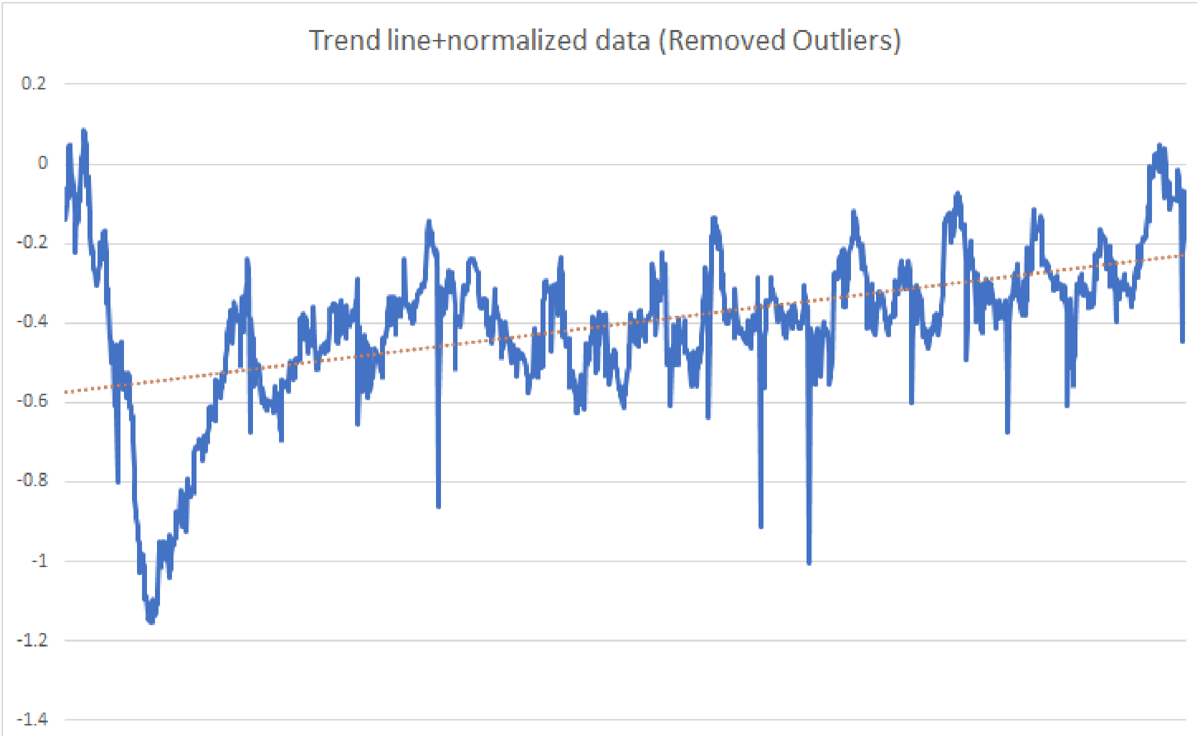

Figure 25: *Example of trendline and pupil dilation progression for one of the participants while reading "Note 9".*

SUMMARY			Alpha	0.05		Hyp Mean	0	
Groups	*Count*	*Mean*	*Std Dev*	*Std Err*	*t*	*df*	*Cohen d*	*Effect r*
First value	*9*	*-0.04299*	*0.0838*					
Last	9	0.028847	0.105687					
Difference	9	-0.07183	0.062902	0.020967	-3.42592	8	1.141974	0.771148
T TEST								
	p-value	*t-crit*	*lower*	*upper*	*sig*			
One Tail	0.004504431	1.859548			yes			
Two Tail	0.009008861	2.306004	-0.12018	-0.02348	yes			

Figure 26: *Repeated measures T-test values for start and end values of trendline).*

10 Discussion

10.1 Bias

An exploratory study such as this, presents multiple biases, which is important to be aware of, for eventual future works. Hence, the following sections, will seek to disclose.

10.1.1 Eyetracking

10.1.1.1 Illuminance

Pupil dilation is an evasive meaurement, as it is known to be affected by multiple varying elements. Pupil dilation is thus known to react to e.g. emotion, anticipation, fatigue, sickness and drugs[42]. However, one of the most problematic elements for recording eyetracking data can be said to be *illuminance*.

Illuminance plays a big role in non VR-based experiments utilizing eyetracking (and hereunder especially pupil dilation), as the physical environment in which the experiment is conducted, can theoretically have infinite variations of illiumination between trials. Since the pupil reacts to light, the lighting conditions in the physical environment surrounding the experiment can greatly influence the data, if not accounted for [42]. Because of this, experiments working with pupil dilation often employs a baseline to account for the potential varying lighting conditions between trials.

However, for eyetrackers built into a VR headset (as the headset used in this study) the illumination from the physical environment is much less prone to affect the pupil dilation, as the headset is designed to avoid lighting from the surrounding physical environment to infiltrate the area around the eyes. Hence, the illumination instead only comes from the screens in the headset itself, and as such can be controlled virtually, and are thus consistent for all subjects.

This poses the question of whether or not our chosen baseline accounts for differing lighting conditions? As our experiment is not conducted in a static environment, we argue that the lighting conditions vary within the virtual environment to an amount where a general baseline is inappropriate, especially since the subjects are free to move around, and thus spend varying amounts of time in each location of the environment. As such, we argue, that a baseline extracted before the onset of the experiment (e.g. in a simulated environment containing varying conditions similar to those in the actual experiment) would prove ineffective at best. However, as the level consists of several rooms that have different light sources, another option for a general baseline, could be for each room individually, which possibly could be enough to register cognitive changes. Such a baseline would give a longer period from which to register a baseline, and as such could be argued to be better for extracting a representative mean. However, even if a longer baseline could be argued to be better to account for lighting conditions, it has likewise been argued that longer baselines are potentially prone to more noise by random fluctuations of the pupil [55]. We believe that our selected baseline for "Note 9" is therefore viable as it registers the pupil dilation immediately before the stimuli and as such in the current illumination, meaning that changes higher or lower than the baseline can be construed as something other than lighting (in this case cognitive processes).

Following this, we will discuss different options for alternative baselines.

10.1.1.2 Baseline

As we mentioned in the previous paragraph, baseline selection plays an important role in data generation and extraction. In theory a perfectly established baseline allows researchers to have a standard value for general pupil dilation devoid of noise inducing influences. As such a "perfect" baseline can be used to isolate the effects of the designed stimuli. As described previously, due to the varying lighting conditions in the experiment, we chose not to record a pre-experiment baseline (see section 9 and 10.1). Nevertheless, we acknowledge that setting another baseline, hereunder a pre-experiment baseline, could potentially allow us to see a more clear picture of the overall trials, as compared to what we got with the current baseline selection. As such, we propose that specifically testing for the proper kind of baseline for the particular study (e.g. short vs. long baseline and pre-experiment or during), could prove beneficial.

To further extend discussion, the baseline option that we decided for this experiment might need to be shorter or longer to properly showcase a change a pupil dilation overtime. Furthermore, a baseline for the cognitive activity of reading might also be of value, to further deduce the specific cognitive effect of the stimuli (e.g. in this study the use of hindsight/foresight while reading, as opposed to "only" reading). By utilizing such a baseline, we would be potentially be able to expand our exploration of the timing of the hindsight, as we would then be able to compare if the increase in pupil dilation during the reading of "Note 9" is actually due to hindsight/foresight or only due to the activity of reading. Hence, we could potentially better detect if hindsight, for example, might happen *after* the reading activity rather than *during*. This could be valuable information concerning the workings of hindsight and foresight; e.g. are they incorporated into the reading activity and happening while new information is being received or do they first activate after the new information is retrieved and as a whole compared with our previous memories.

Another possibility for a baseline, is to electronically measure the actual illuminance level within the headset during the experiment, in order to very accurately take the recorded illuminance into account, even for an experiment in VR[17].

10.1.1.3 Lack of calibration

An important factor for the overall results, must be said to be a lack of calibration of the eyetracker for each participant before the start of each trial. After conducting all tests, we found that the calibration step was overlooked. Consequently we ran several tests using ourselves as subjects, to examine the potential influence this missing calibration might have on the results. After analyzing this data, we found that data has a mean of 0.15mm deviation comparing the non-calibrated eye data with the calibrated. The deviation between participants could potentially be even higher, suggesting that our produced data could be way cleaner and with less disconnections from hardware side if a proper calibration was performed prior the experiment. Even though we acknowledge this oversight, it must be noted as well, that the conditions were the same for all participants, and as such the risk of erroneous data is similar for all participants.

For future works, it would be however be favorable to run the same experiment with an included baseline and eye-tracking calibration to see if there is any deviation from the result we gathered after this experiment.

10.1.1.4 Lack of markers

Lack of markers in the data was the source of some problems, as the data needed to be sorted by the objects that the participants looked at during specific moments in time. By utilizing markers controlled by the testconductors, would have allowed us to separate values by manual actions, such as exiting of rooms or picking up notes and narrative objects, allowing us to analyze data faster and more accurately, and without manual sorting by object names. It would also help us to exclude the portions of the data set where the players were paused and interviewed.

10.1.2 Participants

10.1.2.1 Convenience sampling

Our sampling of participants was done solely through convenience sampling, having recruited friends or colleagues. Because of this, interests and age were relatively similar to our own, though their experience with VR differed to some extent. Since they were familiar with us, the test conductors, the tone did end up more jovial and friendly in nature, although we tried to keep it neutral during interviews. However, since there was no anonymity between test participants and conductors, at least during the experiment, the test participants might potentially have been "afraid" of disappointing us. As such, they might have sought to give us the answers they believe we wished for, rather than what we actually desired; their experience. This situation was tried to be avoided, by specifically informing the participants that there was "no right or wrong answers". Albeit, this issue could have further been reduced by having a much larger sample of participants with differing backgrounds.

10.1.2.2 Different backgrounds

Participants could have been more diversified demographically, e.g. in age, interests and narrative experience. Instead of having all participants be between the ages of 20 and 30, it could be interesting to see an older test group and how they would have reacted to a story which was rooted in loss and marriage. Another interesting divergence in background would be interests, as most participants had great experience and interest in virtual games, having a great deal of precognition with them. Participants without these understandings of games, and what to expect, might for example not expect a "jump scare" to happen as participant 2 did (see appendix no. 11).

10.1.2.3 Interests in narratives

While we did not ask nor ensure any interests for narratives in our participants, it could have had an effect on the results. More importantly, a lack of interest or a very great amount of interest within the group could have found discoveries which we would not otherwise have, in the exploratory setting of the experiment. It could be correlated with both speed and strength of foresight, if for example a participant was greatly interested in interactive narratives, which could be hinting at when foresight or hindsight happened, if they were talking out loud.

10.1.3 Interviews

As mentioned previously, one bias in the interviews could be the familiarity of the participants to the conductors. This could, however, also be regarded positively, as it could mean that the participants felt more safe and comfortable with the conductors. Beyond that, the exploratory nature of the experiment meant that the questions were not designed around any factual checklist of narrative understanding within the cannon story of the game, but rather sought to examine whether or not the participants had any foresight or hindsight. However, in the process of analysing the data we came to a discovery of differential groupings within the participants, depending on their understanding of the story, to correlate with the pupil dilatation. One of the ways we attempted to group the participants were on their understanding of who they were playing as a character and when they discovered it, but our questions were not aiming towards that, so there was a bias of subjective analysis in it, which is also why the groupings were scrapped as a viable correlation.

10.1.4 VR novelty

The novelty of VR as an experience, can also be seen as a bias for some participants as the technology is not as accessible and common as a standalone PC or console game. With the novelty of VR we might explain why some participants did not understand the narrative, because they were more fascinated by the possibilities in VR. We could argue that we could have gotten participants that were acquainted with VR technologies, but we claim that it is a side effect of having the convenience sampling. Additionally, the narrative was designed to give the participants ample time in the beginning to explore the possibilities of the world presented, before the story culminated. In addition to this, the experiment and study we conducted should be considered a pilot test and these variable are not as important, but we find that it should be taken in consideration in a more serious study.

10.1.4.1 Different experience

Different life experiences could also help identify what will happen next based on our own experience. It also would explain why some of the participants figured out the story way before it the ending. Some participant might have encountered similar narratives through books, news, stories on the Internet, etc. It could be useful to include a demographics questionnaire for future experiments. Although, we argue, that the main focus of this experiment was not the cohesiveness of the narrative, but rather the changes in perception of the narrative by introducing new narrative objects.

10.1.5 Reading

We could argue that the overall increase while reading note 9 can be linked to the increased cognitive load, simply being the act of reading the note. However the increase can be linked either to an increasing difficulty of the reading material or an increase in mental workload because of the hindsight/foresight processes that are happening while reading the notes. After re-evaluating the "scanned" information and related information, both information stacks are being rewritten in our brain and then stored in our memory. In some way, hindsight/foresight was happening each time we provided them with new information. Nevertheless, it would be still interesting to test this theory for validity.

Next possible bias introduced due to reading is the difference in the length of the notes. The extracted data showed that participants spent more time looking at note 1 and 9, suggesting that they are the most important ones. On other side, these notes are the longest one in terms of text, meaning that overtime the increase of pupil dilation could be directly linked to complexity and length of the text. The combination of reading and the length of text could be a strong bias, which does not allow us to state that the overtime increase of pupil dilation are linked to hindsight/foresight.

10.1.6 Trend line

Even though the trend line visually shows how the pupil dilation is increasing/decreasing, it can be argued that the begin and end values cannot be compared to each other. We still argue that if there were no difference between the beginning and the end of the overall fixations on objects, the trend line would then be a horizontal line, which would be another indication to that there is no difference in pupil dilation. But in our case, the trend line is rise (8 of 9 participants) which could hint to that there is something happening while the participants looks upon or reads a note.
The only negative trend line was for one of the participants who took off their glasses, which might an explanation, though it must be tested with a larger sample size of bespectacled participants, to see if this trend line decrease was due to this.

However we argue that something is indeed happening to the participants as they read the note, with correlates well with 8 out of 10 participants, found that the final note was the most vital for their understanding of the narrative, with the remaining two having figured out the narrative before they reached the final note. One of these two being the only one with a lack of a positive trend line, which could also explain why it was not rising. Participant 2 simply figured out the narrative before note 9, and thus there was not a great amount of mental processing for a story they already knew.

10.1.7 Different experience time

The difference in experience length for each participant could be a bias as well. This difference would mean that the participants had different time spent on narrative objects, meaning that some participants would have a higher grow in the trend line, compared to others. We argue that a fixed length of the interactive experience is to much, and would create more issues than it would fix. Firstly, each participant will have their own pace of progress because of their physiological tendencies. For example, one participant can be extremely attentive, meaning that they would spent more time "scanning " the environment for narrative clues when another participant would "sprint" through the experience without realizing the importance of some narrative objects. Secondly, if the experiment would have had a fixed length, it would create additional tension for participants to complete narrative in time.

10.1.8 Psycho-physiological measurements with subjective measurements

10.1.8.1 Fixations and pupil dilation

For clarity of results, it would be useful to have the same analysis we did to all pupil dilation values on note 9, for each fixation that has landed to note 9. If we then observe the pupil dilation values for each participant on note 9(see Appendix no. 15), we will see that there is several drops that can be interpreted as ending of old dwell and start of a new dwell. However we cannot claim it without having this analyzed or visually separated. For future works it would be useful to group all pupil values into fixations or saccades and have individual plots for each fixation and saccade, to see if there is a rise overtime for each fixation. Rising tendency would then support the trend line, introduced earlier in 9.4 section. The rising tendency can then be linked to an increasing mental workload or cognitive overload, which can then be linked to the enabling of new cognitive processes as interpretations, evaluation of information, and lastly hindsight or foresight.

10.2 Discoveries

The two players who guessed the so to speak "twists" of the story the fastest, that David is dead and that the player in fact have taken on the role of Margharet, were the only ones not to emphasize a great importance on note 9, but rather the porch note, note 6. The theory here is, as always was although the narrative was designed around the great reveal being in note 9, is that hindsight and foresight is strongest when the individual player figures out the truth of the text, rather than when the text itself tries to define it. In other words, it is not up to the author, if a potential reader shows foresight faster than expected.

10.3 Positive notes

10.3.1 Level design with combination of narrative

The overall design of the prototype is a success, having been designed around creating an increasing interest in the narrative that culminate in hindsight at the finale, the ninth note. The story and level design was shaped after the Hindsight/Foresight Feedback-loop we created, which has been introduced previously (see fig. 6). Since the overall trend was exactly this, with 8 out of 10 participants reporting the final note as being the most important for their understanding of the story, even if it in fact did not show any significant difference in the eyetracking data except on the trendlines (see section 9.4). Only by combining it with previously gathered information, thus indicating our hermeneutic understanding of memory and hindsight/foresight had merits to it.
Smaller confirmations of the prototypes success were also found, though the small amount of data makes it difficult to conclude anything, the logical conclusions of the narratives timeline greatly assisted many participants in utilizing hindsight for foresight, so that many participants had a suspicion of death in the story, even before they reached the final note (see section 9.4). 5 out of 10 either guessed or suspected that David was dead, just from the hints and the foresight these gave them. At least this is theorized, though where exactly, the foresight came from is unknown, as of now.
A new and improved experiment could be done without changing the prototype. The narrative itself also seemed successful in interesting and entertaining the participants, as one only player seemed to be relatively uninterested in it, participant 5. Of course we did not study how interesting or enjoyable the narrative was, but it has been gathered from the interviews, and from observing the test sessions themselves.

10.4 Improvements

While the house itself did end up being of a high quality, both interior as well as exterior, some of the rooms were less developed as others, mainly due to a lack of free assets which were readily available for implementation. Developing a full 3d house on such a level of fidelity requires a 3d artist on full time. Of course, the prototype did not require that many objects, but some more would increase the feeling of the house being "lived in". So, as long as the quality is at the same level as the current prototype, additional objects would work to improve it, and thus the immersion, and hopefully the narrative effect on the participants.

10.4.1 Larger amount of test participants

As with every experiment, a larger amount of data gives a greater possibility to show any concrete proof. In the current state, one participant that shows discordant data is an outlier, but still fills up 10 percentage of the data set. If the trend continued for 10 out of a 100 participants something could be said with more certainty, but as of now is of no major importance as it is a pilot study.

11 Future work

11.1 Introduction scene, abstract one for tutorial and baseline and calibration

For any future experiment, conducted in this direction, the modified version of implementation could be used. Primarily, the introduction scene could be implemented so that it would fit several requirements:

- Introduction to VR as technology.
- Introduction to the environment.
- An environment that allows us to create baselines for different illumination as well as different condition/levels of cognitive load (looking versus reading)
- Calibration of the eye-tracker hardware

Having this scene before interactive experience would allow us to exclude big biases from the data, which means we will have stronger grounding to state that increased or decreases of pupil dilation are related activity of Hindsight/Foresight Feedback-loop. Although, we still need to do proper research to find out what length of baseline needs to be taken. The Chen *et al.* experiment took a baseline by changing lightning conditions *..from complete darkness to bright whiteness over 60 seconds in 9 steps increments of brightness.*[17] We could use this approach with a introduction of additional baseline for reading, which would be implemented in the same way. In could be argued that baseline for reading is not needed because it can include cognitive processes such as reading, but to state that more in-depth "state of the art" review needs to be done. In terms of calibration we would use inbuilt calibration functionality, provided by HTC Vive Pro Eye virtual reality helmet.

11.2 Questions to be used for word mining

With the end of the exploratory phase of the thesis, a future version of the experiment could involve a questionnaire about the focus areas we discovered where the confusing. Points of interests are as following:

- The fate of David Green.
- Who is the player character.
- What the lawsuit was about.
- What David Green suffered from.

Additional smaller narrative points could be the type of mine the accident took place in, the geographic area David and Margharet lives in and perhaps when and how they split apart. The reasoning for these questions could be two fold, for two different methods. The first method could be to mine the answers for words which correlated to these questions and how early they appeared, to compare them between the participants. This could then be correlated to the psycho-physiological measurements to see if they had any effect on the results. The second method was to utilize a point based questionnaire, perhaps using a likert scale, to grade the answers, once again to see how well the participants understood different parts of the story, or perhaps how much they enjoyed it. Enjoyment could be another correlating factor to check for hindsight or foresight.

11.3 EEG

Finally, the most important or significant addition to the experiment would be EEG, or electroencephalogram, to test for any signal activity in the brain, especially during the focus areas we already mapped during this thesis. The studies by Klimesch *et al* [47] could be very interesting to further correlate, with their focus on alpha and theta band power increases and decreases during semantic and episodic memory [47]. Naturally, due to the prototype being made for virtual reality, and thus requiring a headset, it could be difficult to also mount anything but the most subtle and non-intrusive EEG headbands as well. EEG could then be an addition to advancing from an exploratory approach, in order to confirm the indications which were found in this thesis.

12 Conclusion

In conclusion, this thesis was an attempt to identify an activity of hindsight or foresight in an interactive narrative using psycho-physiological measurements. Because of the tight link between hindsight and foresight [52, 44, 76] the Hindsight/Foresight Feedback-loop 6 was developed. In order to conduct the experiment and test the Hindsight/Foresight Feedback-loop, virtual reality as a medium was selected for such reasons as full control over the narrative trajectory within the environment. For the main psycho-physiological measurement, we chose pupil dilation, as an increases in pupil dilation has a correlation to increases in the level of cognitive load [42].

To conduct the experiment, the narrative was constructed based on the Hindsight/Foresight Feedback-loop, and the digital level for the interactive experience was build using Unity3D game engine. The data was gathered using HTC Vive Pro Eye in-build eye-tracker and SRanipal eye tracking API.

After analyzing the data from the subjective measurements, the most important temporal window was identified. The temporal window was analyzed by comparing the baseline values with the mean pupil dilation values as participant looked at important narrative objects, however in the end there were no significant difference. Although, the start and end values of trend line showed significant difference (see section 9.4.

In the end, the experiment results showed that the participants showed activities similar to what we would expect of the Hindsight/Foresight Feedback-loop, shown through the trend line, although it can be argued that it can be linked to other cognitive processes such as reading, which also can be related to cognitive load.

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