

UNIVERZITA KARLOVA

Filozofická fakulta

Katedra psychologie



DIPLOMOVÁ PRÁCE

Bc. Natálie Šimčík

Effect of Screen Size on Boundary Extension

Vliv velikosti obrazovky na boundary extension

Praha, 2022

Vedoucí práce: Mgr. Jiří Lukavský, Ph.D.

Acknowledgements

I would like to thank my thesis advisor and other kind people for their patience, helpfulness, and support.

Declaration

I hereby declare that I have prepared my thesis independently. All sources, references, and literature used or excerpted during the elaboration of this work are properly cited and listed in completed reference to the due source. Thesis was not used at another university or to obtain another or the same degree.

Prague, 29.7. 2022

.....

Bc. Natálie Šimčík

Abstract

When observing and remembering a scene, memory errors can occur, one of them being the boundary extension. This cognitive phenomenon causes people to remember parts of the scenes that might be present just beyond the boundaries of a presented scene but were not actually seen by the observer. Thesis focuses on the aspect possibly affecting the boundary extension, precisely the screen size, which was linked to cognitive phenomena such as memory or attention in previous studies. First part of the thesis consists of a theoretical overview introducing the scene perception topic and mapping the boundary extension findings. Second part of the thesis describes the experiment results to investigate whether screen size affects the boundary extension. No significant effect on measured boundary extension was found in two selected screen sizes, mobile and desktop.

Keywords

boundary extension, screen size, cognitive psychology, scene perception

Abstrakt

Pozorování a zapamatování scény může vest k různým paměťovým chybám, jednou z nich je boundary extension neboli rozšíření hranic. Kognitivní fenomén rozšíření hranic způsobuje, že si lidé pamatují části scén, které mohly být přítomny těsně za hranicí fotografie, avšak ve skutečnosti nebyly vidět. Tato práce se zaměřuje na aspekt, který může mít vliv na rozšíření hranic – velikost obrazovky, která byla v předchozích studiích spojována s kognitivními jevy, jako je paměť nebo pozornost. První část práce se skládá z teoretického přehledu, který nejprve uvádí do tématu vnímání scény a dále mapuje poznatky o rozšíření hranic. Druhá část práce popisuje výsledky experimentu provedeného za účelem zjištění, zda velikost obrazovky ovlivňuje rozšíření hranic. Pro účely experimentu byly vybrány dvě rozdílné velikosti obrazovky, monitor stolního počítače a mobilní displej. V rámci provedeného experimentu nebyl zjištěn významný vliv velikosti obrazovky na naměřené rozšíření hranic.

Klíčová slova

Rozšíření hranic, velikost obrazovky, kognitivní psychologie, vnímání scény

Table of contents

1. INTRODUCTION	8
2. SCENE PERCEPTION	10
2.1. Low-level representations	11
2.2. Mid-level representations	11
2.3. Gist	13
2.4. High-level representations	15
2.5. Memorability of the scene	17
3. BOUNDARY EXTENSION	18
4. RESEARCH OF BOUNDARY EXTENSION	19
4.1. Establishing the boundary extension as a concept	19
4.2. Broadening the theoretical background and proving the robustness of boundary extension	21
4.3. Exploring possible factors affecting the boundary extension	23
5. THEORETICAL ACCOUNTS OF BOUNDARY EXTENSION	29
5.1. Perceptual Schema	30
5.2. Memory Schema	31
5.3. Extension-Normalization	32
5.4. Multisource Model	32
5.5. Source Monitoring	33
5.6. Scene Schema Model	34
5.7. Attentional Selection and Focus	35
6. PRESENCE	36
6.1. Involvement	38
6.2. Immersion	40
6.3. Effect of screen size on presence, immersion and scene memory	42
7. CURRENT EXPERIMENT	43

8. METHOD	44
8.1. Participants	44
8.2. Procedure	44
8.3. Stimuli	49
8.4. Apparatus	51
9. ETHICS	52
10. DATA ANALYSIS	53
11. RESULTS	54
11.1. Descriptive statistics	54
11.2. Mixed model results	58
11.2.1. Linear mixed model – Boundary extension	58
11.2.2. Linear mixed model – Confidence	60
11.2.3. Linear mixed model – Boundary Extension positive confidence subset	62
12. DISCUSSION	65
13. CONCLUSION	69
RESOURCES	70
LIST OF USED ABBREVIATIONS	83
APPENDIX A – INFORMED CONSENT	84
APPENDIX B – FORM	85
APPENDIX C – INSTRUCTIONS	86

1. Introduction

This thesis focuses on the memory error called boundary extension. Boundary extension can occur every time we observe a scene presented to us. Most commonly being explored on pictures or photographs of scenes, subjects tend to remember a bigger portion of the scene that might be just beyond the border of the image but was not, in fact, presented to them.

Studies discussing this phenomenon have been emerging for over thirty years, proving its robustness. However, a lot is still yet to be uncovered, inspiring the main aim of this master's thesis. Previous research focused on many aspects possibly affecting the boundary extension, including intraindividual aspects such as attention or stimuli-related aspects such as object size or aperture. Moreover, following the latter, the stimuli-related aspect will be examined as part of this thesis, specifically the screen size.

Being overwhelmingly the most, yet not exclusively, tied to the visual perception of the scenes, the first chapter of this thesis aims to be a brief introduction to the topic of scene perception. Focusing on the scene representations and processes on multiple levels, but also providing more narrowly focused information about the scene gist and scene memorability, concepts related to the boundary extension quite closely.

Following chapters explore the boundary extension solely, easing in with the introduction chapter and providing an overview of what to expect from the phenomena—then moving into the research papers walkthrough, since the boundary extension knowledge is built mainly on experimental studies and still lacks monography. The third chapter in this cluster is dedicated to different possible theoretical explanations of the boundary extensions, some being unique, others overlapping with each other.

Next chapter is focused on the presence phenomena and its aspect immersion, which is more closely tied to the screen size, and closes in the theoretical part with a brief overview of studies focusing on screen size, memory, and immersion.

The empirical section of the thesis opens with a chapter describing the study's aims, stating the research question and hypotheses. Followed by the eighth chapter presenting used methods for answering the research question, closer explaining the experimental method and. The ninth chapter briefly states the ethics of the experiment precedes chapter about data analysis. The eleventh chapter discusses the results and puts them into context in chapter twelve – Discussion, exploring the limitations of the study as well as possible future improvements. Finally, the last chapter, Conclusion, finishes the whole thesis.

2. Scene perception

For most of us, our daily life is among many other processes filled with observing scenes and extracting information from our observations, whether we are looking at the trees in the park, on our bookshelves or remembering where we parked our bicycles. Even though scene perception can be described quite simply – as an environment perceived by the observer at a given time, a complete understanding of the processes going on when the observation occurs is far more complex. It has been proven that our intuitive impressions of a scene, such as its stable picture-like information, are more of an illusion than a reality (Rensink, 2000).

The complexity of scene perception emerges with the first question we might ask: What is a scene? Typically, a scene is defined as a view of a real-world environment which is semantically coherent and usually also nameable (this topic is further discussed in the subsection Gist). Scene consists of an immovable background and multiple objects located in a spatially licensed manner which can be, in contrast to the background, moved (Henderson & Hollingworth, 1999). Epstein (2005) further operates with this definition and writes about the contrast between scene environments and non-scene objects. Simplifying the definition with a heuristic that scenes are spatially distributed entities that we act within, and objects are spatially distributed entities we act upon.

Scene perception research has evolved throughout the years. Scene representations are no longer thought of as being built up by eye movements and attentional shifts but rather by creating structures rapidly, which helps with guiding spoken oculomotor activity (Castelhano & Williams, 2021) Multiple levels of processing are taking part in scene perception and scene understanding, from low-level processing, where raw and simple information about the scene is sourced in milliseconds (Marr, 2010), to high-level processing, which allows us to expect which objects could be present in the perceived scene (Rensink, 2000). Those levels are usually perceived as hierarchically ordered due to their seriality of discrete stages producing increasingly more abstract representations (Groen et al., 2017).

2.1.Low-level representations

On the low level of processing, information about basic features of scenes is obtained from the light falling on the human retina (Marr, 2010). Details about object colour, contour, spatial frequency, orientation, intensity, and luminance are gathered (Borji et al., 2013; Peirce, 2015) and further processed into the raw sketch (Marr, 2010). This sketch is, however, very volatile and exists only until the next eye movement and thus must be constantly regenerated by creating new sketches with every eye movement (Rensink, 2000). Features observed on this level, as well as second-order features like intersection and edges (Erdem & Erdem, 2013) also contribute to eye-movement planning utilizing the extracted low-level information in saliency maps (Castelhano & Williams, 2021).

2.2.Mid-level representations

Mid-level representational processes are, in comparison with low-level and high-level ones, less researched and also less understood. However, as their name suggests, they are considered to be the bridge between unstable volatile low-level and more permanent high-level representations (Peirce, 2015). Mid-level representations are built up from features such as spatial layout, surfaces, textures, and shape features (Groen et al., 2017), but computing also with the information about object borders and structures between edges (Dimitrov et al., 2012). Obtained data about elements are further complexly processed utilizing the working memory, resulting in creating an integrated percept where objects can be distinguished from the (Kandel et al., 2014; Rensink, 2000).

Working memory is a crucial part of mid-level representations and processes, enabling storing specific complex features of the perceived scene, such as object structure, scene layout and gist (Rensink, 2000). However, according to other authors (Oliva, 2005), gist hierarchically belongs to the high-level representations or somewhere between mid-level and high-level and thus, for purposes of this thesis, will be described in a separate subsection.

Object structure

Detailed information consisting of low and mid-level features such as colour and shape about low number of objects can be stored across the eye movements. This information is stable while focusing on the object, and only a few items remain after shifting the focus (Irwin, 1996). Visual memory is accountable for the construction of individual objects, and only a limited amount of object representations can be worked with simultaneously at a given time (Rensink, 2000).

Scene layout

Global properties discerned by the mid-level processes such as spatial layout (Ross & Oliva, 2010) are at an early stage of vision, contributing to creating a scene layout consisting of recognized ground surface and perceived objects arranged in relation to the surface, but also to each other and the observer (Haber, 1985). Being crucial for surviving in the world, creating a representation of scene layout utilizes a large portion of the brain (Sanocki, 2003). Scene layout has been an essential topic of a significant number of studies in past decades. The discussion was focused mainly on the depth information resulting in studies discovering the importance of shape, texture gradients, edges and junctions, relative size and even elevation (Ross & Oliva, 2010). It was discovered that even very short exposure to a scene layout triggers distance perception (Sanocki, 2003). Studies have also shown that global properties crucial for the three-dimensional layout of the environment (dominant depth, openness, and perspective) are perceived in the first moments of the glance (Greene & Oliva, 2009).

Some authors, such as Hochberg (1978), think of the scene layout as the schematic map, which is rapidly built, describing relations between the objects without detailed information about them. This map is sufficient to provide guidance through the scene (Rensink, 2000).

2.3.Gist

Grasping the main idea of the perceived scene, such as “*forest*” or “*city*”, is a feature of the human visual cognition called *gist*, combining all levels of processing and features. For example, low-level colour and spatial frequencies, mid-level surface and volume and high-level semantic knowledge or identification of objects placing gist outside the borders of hierarchical categories and levels of visual processes and representations (Oliva, 2005).

This process is happening rapidly; recognition of the gist takes place before the first saccade is launched, which is around 200 ms (Rasche & Koch, 2002). Less than 100ms is sufficient for understanding the presented scene; however, consolidation in memory takes additional hundreds of milliseconds. The consolidation is crucial process for expressing a verbal label-like description of the scene (Oliva, 2005). When the labels are known prior to the presentation, the gist can be recognized in as few as 13 ms (Potter et al., 2014). Even though lot of studies describing the gist emerged, it is still not completely clear how the gist is created. Due to the speed of the process, some studies suggest that the processing of different scene features is parallel (Rousselet et al., 2002). Rensink (2000) suggests that gist might be based upon perception and recognition of 2-3 objects; on the other hand, Henderson (1992) presented a theory proposing that gist can be understood without perceiving any objects.

By activating the prior knowledge, gist influences scene processing, affecting attention, memory and possibly also object recognition (Loschky et al., 2010). After retrieving the gist of the perceived scene, additional processing utilizing visual attention on salient locations takes place.

As a result of combining all the levels of features and processes, scene gist can be observed on both *perceptual* and *conceptual* levels (Oliva, 2005). *Perceptual gist* involves properties of perceived image providing a structural representation of a scene. Structural representation is determined by the image properties, such as texture, spatial frequency (Gong et al., 2018), density, scales, and colour (Oliva, 2005). Oliva and Torralba (2001) proposed a concept of *spatial envelope*, a representation of the real-world scene structure, consisting of five perceptual properties: naturalness, openness, roughness, ruggedness and expansion. *Naturalness* depicts the difference in structure of the man-made and natural scene – artificial structures being built on straight horizontal and

vertical lines differentiating themselves from the natural structures with less strict elements. Degree of *openness* is a second major attribute indicating how many bonds perceived scene has – layout consisting of horizontal line without many other reference points. For example, scenes such as those depicting a field have more open layout in comparison to scenes capturing a living room. *Roughness* of the scene describes the size of major elements located on the scene correlating with complexity of the scene. Deviation of the ground on the horizontal line can be described as *ruggedness*, with natural scenes levels of ruggedness being higher thanks to man-made structures being usually built on the flat ground. Lastly, the *expansion* is based on the same expectation as naturalness; artificial structures being built on horizontal and vertical lines but working with this expectation further and adding observer's perspective resulting in converging lines for closed spaces and diverging lines for more open spaces.

Conceptual gist refers to the semantic information extracted during the scene observation or shortly after the presentation and is influenced by the perceptual gist. Semantic information about the scene can be obtained even if the image of the scene is not ideal, or somewhat visually degraded, contains object inconsistencies or is overall presented in a low resolution (Owens et al., 2019).

2.4.High-level representations

Object structure, scene layout and scene gist remain relatively invariant over changing viewing positions suggesting that they can remain constant over long periods of time, forming scene schemes and allowing learning of how often they are present in different scenes (Friedman, 1979). Prototypical scene representation previously stored in the memory is activated during the perception of the scene and provides data for developing likelihood expectations about observed objects. Scene schema influences further identification processes and alters the time needed for identifying perceived objects based on the likelihood of the object being part of the observed scene (Henderson, 1992).

High-level processes are thought to extract data from visual input into categorical or semantic representations, which are necessary for the identification and classification of scenes and objects (Groen et al., 2017). High-level representations are stable over time and also stable to the environment, specifically to the type of lighting, angle, or other distractions such as presence of other objects.

Scene classification

Without categories, every object and every scene would need to be rediscovered every time when seen (Greene, 2019). This would, for example, lead to rediscovering the meaning and usage of the doors every time we would want to enter or leave the room. Scene classification is used for categorizing different images into specific classes such as indoor and outdoor, mountains or urban (Dunlop, 2010). Classification within the categories is crucial for the object and scene recognition, but also for communication the ideas and concepts and are used in a way which is maximizing information transmission between people (Greene, 2019). This shows that classification has a semantic character.

Humans are able to classify both objects and scenes effortlessly; however, the mechanisms and processes of the classifications are still not completely clear (Wilder et al., 2018). For about forty years, the central portion of the theories has been focused on object-centred models of visual recognition (Biederman, 1987; Li et al., 2012; Nakamura, 1994). In those theories, meaning of the scene is derived from the identities of objects located on it. Scene is classified by recognizing several objects occurring together (Biederman, 1987) or one or more prominent objects being present in viewed scene (Friedman, 1979).

Greene and Oliva (2009) propose a scene-centred theory where identification of the objects is not necessary. Meaning of the scene is assigned based on the structure of the whole scene and its properties independently of the object recognition, which can, however, be happening parallelly. Properties used for scene recognition and classification are divided into three categories – properties of the scene structure, constancy and function.

2.5. Memorability of the scene

This thesis is focused on the boundary extension, classified as a memory error. Majority of the experiments utilize experiments based on memorizing and recognition of the scenes for its measurement. Memorability of the scene is thus an essential aspect of scene perception that should not be overlooked.

As was mentioned in this chapter, humans have ability to remember and recall images even though they were exposed to the source only for a brief time. Nevertheless, individual images are not remembered equally in the human brain, some being remembered long-term in higher detail than others, some stored for longer time or forgotten quickly (Lu et al., 2016). For some pictures, we remember only the gist, e.g. that we have seen *some* picture of a table; for others, we are able to recall fine details like *what* kind of pen was located on the picture, which left researchers with a question of why this happens and what are the mechanics of memorability (Brady et al., 2008; Lu et al., 2020; Lyu et al., 2020; Parikh et al., 2012).

Difficulty of memorizing an image containing a natural scene (Lu et al., 2020), memorability of the scene, might be influenced by the *extrinsic* and *intrinsic* properties. *Intrinsic properties* of a scene consist of global descriptors, object counts/areas, scene category, and aesthetics. *Extrinsic properties* cover all factors outside the picture, which might vary across the subjects, such as order of the presented scenes, where on the picture is subject physically looking (Bylinskii et al., 2015) or observer's expertise (Curby et al., 2009). *Intrinsic* memorability is then independent of past experiences (Bainbridge et al., 2013) and seems to be stable across all the settings, contexts and observers, providing the base level of memorability and *extrinsic* effect being easily marginalized, working as an extra modifier determining if the specific image will be remembered (Bylinskii et al., 2015).

In research of Isola et al. (2011), images depicting enclosed spaces and with people with their faces visible were more memorable. On the contrary, open landscapes and peaceful settings were less memorable. However, in contrast to the previous research, the aesthetics of the picture and its unusualness were not associated with memorability and actually correlated negatively, leaving a space for further research.

3. Boundary Extension

When presented with images of a scene, we tend to remember the depicted scene being a bit wider than it actually was in the previously seen picture. Alternatively, in other words, content of the scene is *extending* over its boundaries formed by the edges of the image. This memory distortion was first described by Intraub and Richardson (1989) and got accepted as a piece of revealing information providing an insight into memory representations (Bainbridge & Baker, 2020).

Thanks to being stably measured across the age groups and even methodological details such as the method used, depictive style or length of exposure, *boundary extension* (BE) is thought to be one of the most robust mapped phenomena belonging to the memory category according to Nanay (2021).



Figure 1. Example of the boundary extension. Left: presented photography; Right: possible remembered scene with extended boundaries (own photographs).

Boundary extension might be affected by the several factors, which Hubbard et al. (2010) sorted into three categories – characteristics of the stimulus, features of the display and attributes of the observer. For measuring boundary extension, a memory test is usually performed, being completed using drawing as in the initial experiment of Intraub and Richardson (1989), photography recognition (Intraub et al., 1996) or more rarely boundary adjustments (Daniels & Intraub, 2006) or zooming in the picture (Chapman et al., 2005).

Even though the concept was first discovered more than thirty years ago, it is still undergoing a quite lively debate, and new acknowledgements are being published almost every year (e.g. Bainbridge & Baker, 2020; Gandolfo et al., 2021; Intraub et al., 2020).

4. Research of Boundary Extension

First observed in 1989 by Intraub and Richardson, research covering boundary extension error has been going on for more than thirty years and went a long way in discovering a plethora of relationships and links, even though much is yet to be unravelled. To this day, researchers at least partially uncovered theoretical background, context, factors influencing the perceived boundary extension, different experiment proposals and even boundary extension taking place not only as a visual phenomenon but also auditory and haptic one. The following section aims to provide the research overview to the reader, starting with the first studies setting the foundation stones of the concept, continuing with using new experimental schemas and widening the theoretical basis and finally, focusing on different aspects affecting the boundary extension and finishing with most current experiments.

4.1. Establishing the boundary extension as a concept

As mentioned before, the first research on boundary extension was conducted by Intraub together with Richardson in 1989. The authors presented 20 close-up photographs of a scene to participants, giving them 15 seconds to memorize each and testing the recall portion of the experiment either 35 minutes or two days later. Participants were asked to draw a subset of presented photographs. Regardless of the condition (35 minutes or two days), boundary extension was detected in 87% – 96% of all instances. The study also consisted of an experiment based solely on recognition, presenting previously seen images with counterbalanced variants: wide-angle photos were tested for recognition with the same wide-angle variant (WW) and the close-angle variant (WC). Close-angle photos were tested with close-angle photographs (CC) and wide-angle photographs (CW). Intraub and Richardson presented participants with the new image and let them compare it to the previously seen one, asking for an indication if the newly presented picture appeared *“the same as presentation picture”*, *“little further away”*, *“a lot further away”*, *“little closer-up”* and finally *“a lot closer-up”* which is a scale used with subtle modifications until this day. Boundary extension was also found in this variant of the experiment.

A study following up on the first one was conducted three years later by Intraub et al. (1992), again using the 15 s presentation time and recollection 35 minutes or 2 days later, utilizing the five-point scale; however, this time, the researchers were focused on finding the reason for boundary extension happening. Intraub and colleagues tested three theoretical explanations for the boundary extension phenomena, specifically the *object completion theory*, *perceptual schema*, and *normalization towards a prototype*. Intraub et al. (1992) rejected the object completion theory in this study and leaned towards *perceptual schema* for immediate response and resulting in the proposal of the *Extension-normalization model* for picture processing. All mentioned theories are further described in the chapter *Theoretical accounts of Boundary extension*.

In 1993, Intraub, together with Bodamer, continued the work on the exploration of possible boundary extension causes, specifically if boundary extension might be eliminated by informing the participants about possibility of the said distortion happening. Again, using the free recall drawing method and recognition method, but this time in three conditions: test informed (subjects were given detailed description of the recognition test), demo condition (boundary extension phenomena was explained to the subjects, and they were instructed to avoid it) and control condition (using the same method as described in previous research – e.g., Intraub and Richardson (1989)). In all cases, boundary extension appeared, which led the researchers to suggest that BE “reflects activation of scene expectations during the perception” (p. 1). However, in the demo condition, boundary extension was in some cases reduced.

This first period did not lead only to the establishing of the concept, but also to establishing the most prominent boundary extension experimental method until this day, specifically the 5-point scale for measuring in the recognition part.

4.2. Broadening the theoretical background and proving the robustness of boundary extension

After establishing the boundary extension in several experiments, new studies followed up with Intraub still being in the lead. One of the first changes consisted of decreasing the presentation times to milliseconds and introducing rapid serial visual presentation (RSVP) to the boundary extension experiments (Intraub et al., 1996). In context of boundary extension experiments, *rapid serial visual presentation* usually follows a fixation screen and tends to consist of one target stimuli accompanied by two distractors in sequential presentation followed immediately by a mask and recognition task.

It was discovered that decrease in presentation times did not eliminate or change the measured boundary extension (Beighley & Intraub, 2016; Dickinson & Intraub, 2008; Intraub et al., 1996) leading to suggestion that scene construction behind boundaries is happening in a rapid manner.

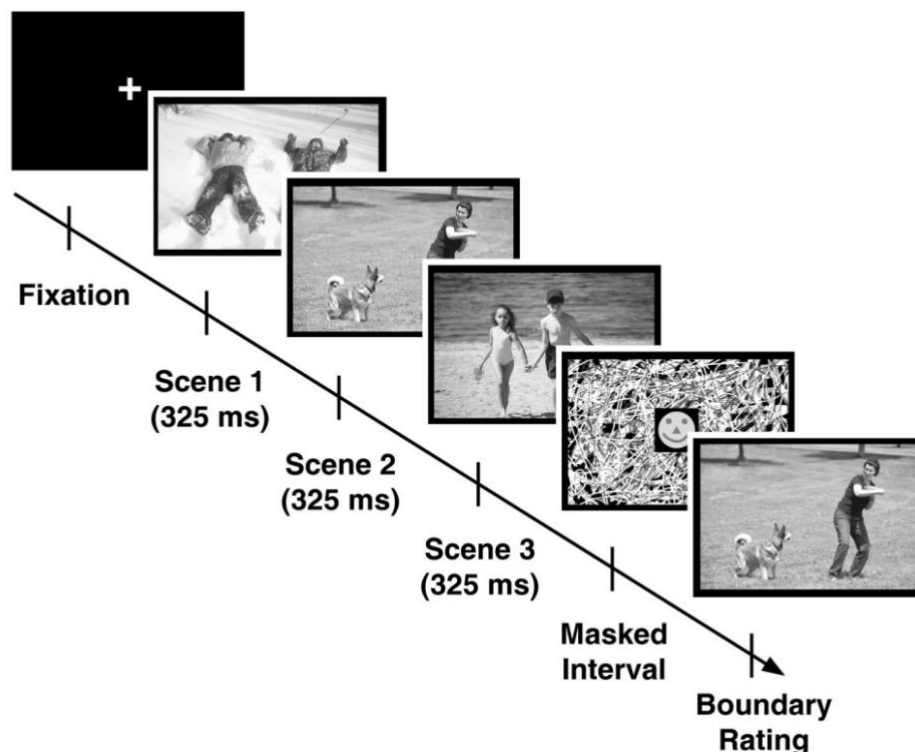


Figure 2. Schema of the RSVP boundary extension trial. From “Transsaccadic representation of layout: What is the time course of boundary extension?“, by C.A. Dickinson, H. Intraub, 2008, *Journal of Experimental Psychology: Human Perception and Performance*, 34(3), p. 547. <https://doi.org/10.1037/0096-1523.34.3.543>

Challenging the distinction between perception and memory, boundary extension occurred very fast after the presentation of target stimuli. Intraub and Dickinson (2008) used masked interval of as little as 42 ms, corresponding to the duration of one saccade, without it leading to elimination of boundary extension. Based on the findings, the authors of the study proposed a multisource model possibly accounting for such rapid occurrence of BE, suggesting that perceptual representation is not drawn from a sensory input as a single source but rather using at least two more internal sources of the scene structure.

This theory was further supported by a study where objects on presented stimuli were cropped on one side with only reducing but not completely removing the overall boundary extension (Gagnier et al., 2013).

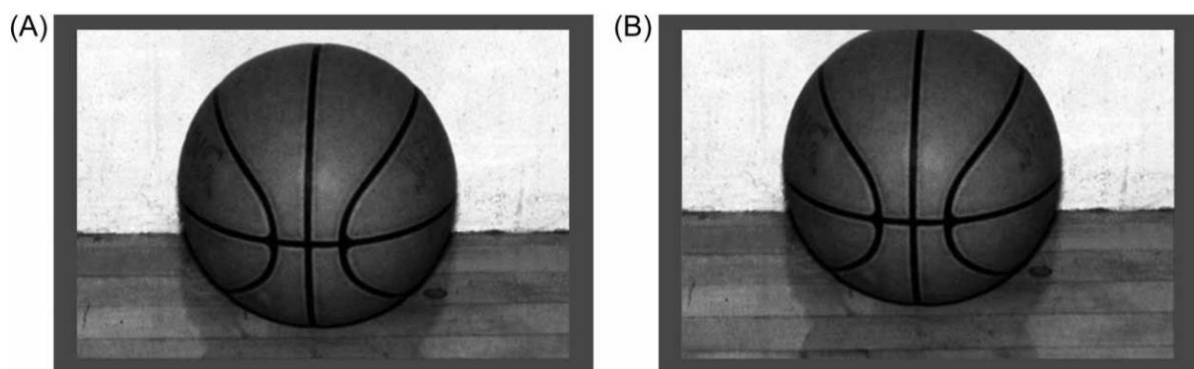


Figure 3. Presented stimuli with one side of the central object cropped. From “Fixating picture boundaries does not eliminate boundary extension: Implications for scene representation.” by K.M. Gagnier, C.A. Dickinson, H. Intraub, 2013, *Quarterly Journal of Experimental Psychology*, 66(11), p. 2165. <https://doi.org/10.1080/17470218.2013.775595>

Besides cropping the object, more stimuli-related factors possibly interfering with the boundary extension were examined. One of them being an inversion of the presented scene. Although inversion might negatively impact the perception (Yin, 1969), presenting inverted scene images to subjects did not eliminate the boundary extension as well, this time further supporting the perceptual schema mentioned earlier (Beighley & Intraub, 2016; Intraub & Berkowits, 1996).

Gagnier with Intraub (2012) tested the boundary extension on single and multiple-object scene photography in comparison with line drawings of the same scenes. Surprisingly, the line drawings yielded higher boundary extension for both single and multiple object scene stimuli. Authors provide a possible explanation that due to higher similarity of visual and amodal information for linear drawings (in comparison to lower similarity for photographs), *source monitoring error* is triggered, and subjects misattribute surrounding space to the perception instead of internal expectations. *Source monitoring error* is further explained in the *Theoretical accounts of boundary extension* chapter.

4.3.Exploring possible factors affecting the boundary extension

Right after the turn of millennium, research of boundary extension became even more niche, focusing on possible factors that might affect its occurrence. Suggested influencing aspects are emotions, age, and type of the presented stimuli. On top of the mentioned aspects, researchers also focused on the clinical population and neurological-oriented studies.

Boundary extension proved to be a stable construct across multiple **developmental stages**. Probably first to examine role of age BE was Seamon et al. (2002) with the wide-range study comparing the first-grade students, fifth-grade students, college students and older adults. Using the drawing method for recollection of 15 s presented stimuli of one or two objects, all age groups demonstrated boundary extension even though children and elderly participants demonstrated higher boundary extension rates than college students. Other researchers came to similar results, Candel et al. (2004) studying children from age ten to twelve and Quinn and Intraub (2007) expanding the age groups to as low as three to seven-month-old infants using purely recognition-based tasks with measuring the children's preferences. Latest contribution was made in the study where two groups of adults, first aged 18-25 and second 72-79 years. Boundary extension was observed in both groups, however in the younger group factor explaining the BE was their cognitive functions whereas in the elderly was explained rather by the intellectual efficiency (Ménétrier et al., 2019).

Emotional context of the stimuli attracted researcher interest multiple times across the thirty years, resulting in conflicting outcomes. Change in the boundaries affected by the emotional context stands on the premise that negative emotions should activate *tunnel memory* resulting in the *boundary restriction*, which is opposite effect to the boundary extension leading to subjects perceiving and reporting image boundaries being smaller than presented to subjects (Safer et al., 1999). Images with negative emotional subtext were investigated four years later by a different group of researchers resulting in finding boundary extension for both negative (aversive) and neutral emotion images (Candel et al., 2003) questioning the statement of the previous research group suggesting that perhaps boundary extension phenomenon is more robust than the tunnel memory one and further backing the idea of boundary extension happening on the early perceptual level rather on the later memory level of processing. Year later Candel et al. (2004) conducted an experiment with emotional and neutral pictures once more, this time their subject group consisting of children between 10 and 12 years. Even in this experiment boundary extension did not differ between neutral and emotional stimuli in the drawing task. In the latest study on this topic by Beighley et al. (2019) also did not measure differences between stimuli containing human faces expressing negative and positive emotions and thus leaving the debate with more questions about the effect of tunnel memory on boundary restriction.

Possible explanation of the initial findings by Safer are brought by Takarangi et al. (2016) who focused on measuring the emotional context affecting the BE in context of measured mood, PTSD symptoms, processing style and experience of intrusions. Most participants once again remembered the initial photographs as bigger than presented in the remember suggesting that the displayed images were not traumatizing and negative enough to possibly trigger the boundary restriction. Extent of traumatic aspects of stimuli reexperience predicted the boundary restriction. Based on the findings, authors suggested that boundary restriction might be connected to the intraindividual differences in post-trauma coping mechanisms (Takarangi et al., 2016).

Clinical population-centred stream of studies emerged in 2000s, being represented by study of Chapman et al. (2005) who performed the experiment on neurotypical adults and boys aged 9 to 16 years with and without Asperger's syndrome. In this study, less usual test method was utilized, specifically the *zoom method*, where subjects in memory part of the experiment are instructed to use the keyboard to adjust the image by zooming in or out to match the previously presented stimulus. Boys with Asperger's syndrome displayed similar levels of measured boundary extension as their neurotypical counterparts in the control group. Interestingly enough, high performance IQ accounted for high levels of boundary extension in subjects with Asperger's. The effect was opposite for boys in the control group. Targeting specific brain areas more finely, Mullally et al. (2012) examined patients with amnesia and hippocampal damage to discover that those patients had lower measured boundary extension when compared to the control group. Following up on studying the influence of hippocampal damage, De Luca et al. (2018) examined *hippocampal* and *ventromedial prefrontal cortex* (vmPFC) patients discovering that both groups showed attenuated boundary extension. Based on the results, authors suggesting that hippocampus and vmPFC are essential and complementary to the scene construction processes.

Major part of the studies provided new insights into the **specifics of the presented stimuli** extending the knowledge of the influence of interindividual differences and following the emotions-related discussions. Opened in the previous subsection with the object cropping, shortening the presentation time and inversion, multiple more aspects of the stimuli were explored in previous studies. Starting with the viewing angle, effect of the vantage points has been studied revealing that pictures taken from a 45° view yielded smaller BE than pictures taken from the central point of view. Possible explanation suggested by the authors is based on the premise that scene representations use global characteristics for 3D world construction. Pictures taken from the 45° view display more of the 3D scene than the 0° (central) view which display less of the background increasing the expectations of background continuing unchanged and thus increasing the BE (Gagnier et al., 2011).

Another researched stimuli-related aspect is form of the scene. Gagnier and Intraub (2012) combined single object (one central object on the picture) and multiple object (more complex scene) stimuli and compared colour photographs of the scenes and line drawings of the scenes. Even though the line drawings and photographs shared many aspects, such as the gist, objects' relation to the boundaries or the layout, experiments resulted in line drawings yielding higher boundary extension.

Even though being closely tight to visual memory and viewing the scenes, selected **other senses besides the sight were experimented with in context of the BE**. Starting in the 2004, Intraub et al. used new experimental method to assess the BE in blind and deaf participant, 20 blindfolded participants and 20 sighted participants. Sighted participants had to explore physical scene consisting of several placed objects visually, second group (blindfolded participants and blind and deaf participant) explored the scene blindfolded by only touching the objects inside of the wooden frame. Conditions for both groups are depicted on Figure 4. After 30 s exploration phase, participants were sat in waiting room for around five minutes and administrators of the experiment removed wooden frame for the haptic condition and called the participant back in to assess the scenes and show where the window frame was located before. Administrators marked the position, let the participant re-assess and move the borders if needed. Experimental process for the visual group was similar, just black curtains were used instead of the wooden frame. Both groups (visual and haptic) reported boundary extension as well as

the blind participant who reported similar results as haptic group. Visual group's boundary extension rates were however much higher (visual group reported seeing on average 53% more of the scene in the second part of the trial, whereas haptic group reported on average 17% more).

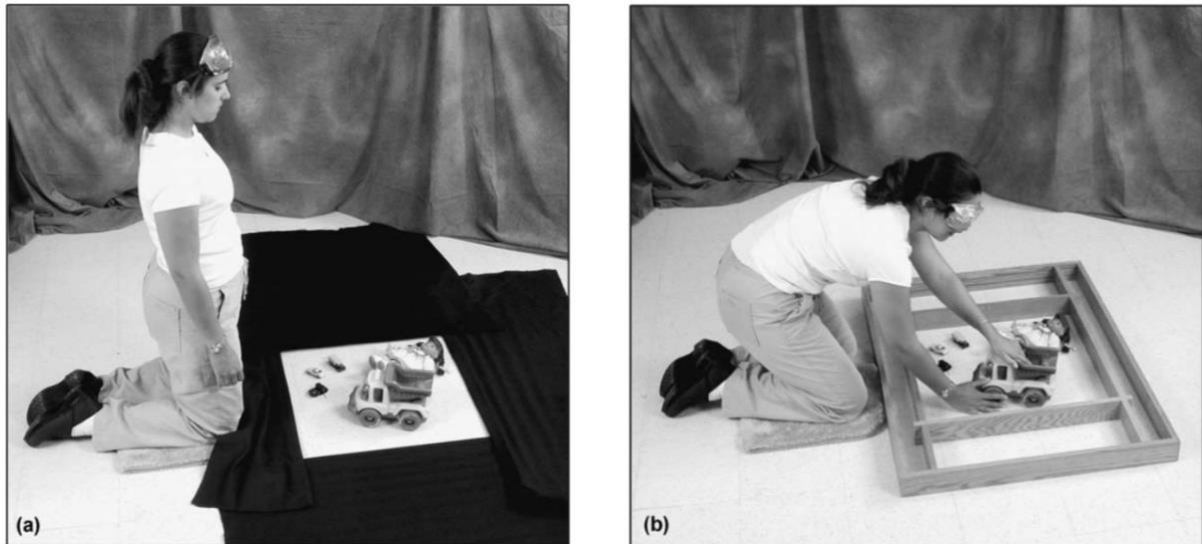


Figure 4. Left: visual exploration. Right: haptic exploration of the scene. From “Anticipatory spatial representation of 3D regions explored by sighted observers and a deaf-and-blind-observer.” by H. Intraub, 2004, *Cognition*, 94(1), 19-37. <https://doi.org/10.1016/j.cognition.2003.10.013>

Even though being much stronger upon visual inspection, boundary extension appears to be an aspect of spatial cognition.

Hutchison (2007) examined boundary extension for auditory senses across multiple types of auditory stimuli – from simple notes to more complex excerpts from music or literature. Participants were instructed to compare probes and stimuli length on likert scale -3 to +3 as well as their tempo. When long probes were followed by equal or lesser length target stimuli, boundary restriction occurred. When using adapted experimental schema of close-up (short), prototypic (same) and wide-angle (long) stimuli commonly used for measuring boundary extension, boundary restriction occurred to the wide-angle (longer) condition. Boundary extension was measured for continuous stimuli (such as music) and not for discrete stimuli (such as literature).

Five years later Hutchison et al. (2012) conducted a new series of experiments with spoken prose and music played to the participants instructing them to remember the content of played stimuli. Boundary restriction was measured across majority of the experiments. When auditory stimuli contained more content, pattern in exhibition of the boundary restriction was stronger.

Even though a lot is still yet to be uncovered, boundary extension has been studied in many possible contexts, with gradually assembling the theoretical background of the phenomena through the experiments.

5. Theoretical accounts of Boundary extension

Boundary extension is a memory error manifesting by remembering more information about the scene that was presented to the observer (Intraub & Richardson, 1989). One of the possible explanations of why the boundary extension phenomenon exists is the effort of our perception system to integrate information from transsaccadic memory for us to be able to understand the whole observed scene. Even though boundary extension is a memory error, it seems to facilitate the prediction of how would given scene continue outside the presented boundary. Integration of the scene views might then be facilitated by boundary extension by both priming the visual scene for the upcoming layout and providing a context to the perceived view (Intraub, 2002).

To this day, agreement on how exactly boundary extension forms was not reached. However, multiple theories explaining possible background emerged over the years, bringing more discussion and new research questions. This thesis will cover the most prominent theories, specifically the Perceptual Schema, Memory Schema, Scene Schema, Source Monitoring, Multisource model and Attentional selection and focus model. Since each of the theories looks at the phenomena from a different perspective, they are not all necessary to exclude each other and actually can coexist.

5.1. Perceptual Schema

The most prominent theory explaining object identification in scenes and providing context for boundary extension is *perceptual schema*. Concept, whereas an essential part of cognitive development, humans create schemas facilitating perception automatically (Friedman, 1979). Perceptual schema proposes that based on prior knowledge, expectations about the scene layout and type interact with perceptual analysis of rapidly extracted relations between background and objects located on the scene (Henderson & Hollingworth, 1999). Information about the objects and spatial relations is stored in the memory representation of given scene type. According to Biederman et al. (1982) scene schema is activated early, facilitating the analysis of objects assessing the schema-consistent objects and recognizing schema-inconsistent objects. Perceptual analysis then might be inhibited for the inconsistent ones. More perceptual effort is needed for recognising the scene and identifying objects when observing combinations of backgrounds and objects that are not occurring together frequently, which is thought to sign perceived scenes being mapped upon the internal mental map model.

Resembling the concept of mental schema by Hochberg (1978), perceptual schema might be responsible for integrating different subsequent views of the perceived scene (Intraub et al., 1992).

Perceptual schema concept initially emerged from experiments performed by Biederman and colleagues (Biederman 1972; Biederman et al., 1973), which was focused on visual search of objects in presented scenes. Researchers jumbled the real-world scenes, so the global relations were altered; this resulted in lowering the accuracy of identifying a cued object in comparison to scenes which were not manipulated, which corresponds to the description of perceptual schema outlined above.

Boundary extension happens because of the activation of the perceptual schema; this concept also helps to explain why close-up views produce more boundary extension than wide-angle views. Close-up views do not provide enough context, forcing the observer to incorporate other sources of input in contrast to the wide-angle views where more of the context and predictable area is already present within the picture (Intraub et al., 1992).

5.2.Memory Schema

The memory schema hypothesis was first proposed by Intraub et al. (1992), suggesting that there is a prototypical viewing distance for each type of scene. Information about viewing distance of a perceived scene is then shifted and regressed towards the prototypical one. Boundary extension is, according to the memory schema hypothesis, caused by the normalisation of a perceived scene to the mental prototype.

Intraub et al. (1992) supported this theory experimentally; in her study, wide-angle scenes were remembered as being closer than they were, which we call *boundary restriction*. Close-up scenes were remembered as being a bit farther than presented, producing boundary extension. Memory schema was applicable in experiments where memory test was delayed in contrast to immediate testing, which pointed out more to the perceptual schema.

Hubbard et al. (2010) noted that memory schema could not account for the explanation of boundary extension alone. He also pointed out that memory schema seems to be aligned with the close-up images, however, it does not explain discrepancies in findings consistency surrounding the wide-angle stimuli that are exhibiting boundary restriction, but also weak boundary extension or no displacement of the boundary location.

Intraub et al. (1992) that although memory schema could account for the boundary extension phenomena, perceptual schema hypothesis seems to be a more comprehensive explanation for the boundary extension phenomenon.

5.3.Extension-Normalization

Extension-normalization model combines two processes contributing to the memory of the scene (Intraub et al., 1998). Those processes are perceptual schema, which was described above, and normalisation. Both influence the mental representations of the scene differently. Perceptual schema works as a mental map providing information about structure and probability of its components being present and probably accounts for close-up pictures being remembered as wider (Intraub et al., 1998).

Second process is called *normalisation* and is focused chiefly on recalling presented scenes over time. Based on the experiments (Intraub et al., 1992), reported boundaries of the images changed over time. Remembered close-up images shifted towards boundary extension, but wide-angle images yielded boundary restriction, which converges to the long-recognised phenomenon of memory normalisation towards most prominent prototype of a given scene.

5.4.Multisource Model

The premise of the multisource model is that perceptual representation is derived from at least two sources at the same time. Both described sources are top-down processes, first of them being amodal perception, second of them is spatial information. According to Intraub (2010), humans have internalised egocentric sense of space filled with information. One of the sources is data from vision, amodal processes and contextual knowledge.

Following up on the object completion concept by Kanizsa (1979), in multisource model amodal processes (processes not utilising sensory modality – for example, even though an object is partially hidden, we remember what the object was, not what we have exactly seen) are holding a function of filling out the occluded parts of object and the continuity of surface textures (Intraub & Dickinson, 2008). Amodal perception is thus responsible even for the occlusion at the boundaries of the view (Gottesman & Intraub, 2003) where a visual system of the observer fills in the missing data on the boundaries of the view with top-down information (Intraub, 2010).

5.5. Source Monitoring

Source monitoring theory follows up on the *reality monitoring model* by Johnson and Raye (1981) which describes the ability to differentiate between memory accounts of real (existing out of oneself) perceived events and memories of one's own thoughts and fantasies. Authors proposed that the external and internal sources of memories are different in the class characteristics. Higher levels of confusion are then caused by the memory similarity between those two sources. Moreover, can be reduced by the amount of known quantitative details about the cognitive operations – memories based in perception tend to be richer in spatial, temporal and sensory data. Assumptions about those characteristics are then part of the metamemory influencing source monitoring decision.

Even though *source monitoring theory* is based on the reality model, it has two key differences. First, theory implies that the quantitative characteristics are only a small part of the memory characteristics possible to use to identify the source. Second, that it switches from dichotomic *external-internal* source to more of a range consisting of finer source details needed for origin specification. Some of those details are spatial and environmental context, temporal context, modality, agent and apprehension (Lindsay, 2008). Boundary extension in the context of the source monitoring error can be explained as being a product of source confusion error by not distinguishing what was actually perceived and how was the scene “understood” (Seamon et al., 2002).

5.6. Scene Schema Model

Scene schema theory is built on the premise that boundary extension occurs, or at least is observed only on static scenes (DeLucia & Maladia, 2006). Theory then explores the context of boundary extension in relationship with *representational momentum*. First documented by Freyd and Finke (1984), term *representational momentum* stands for a tendency to remember moving object's stopping point as further in the direction of movement (Brouwer et al., 2004).

Examining the relationship of the two phenomenon revealed similarities between the two in the previous research (Hubbard, 1996). Similar interactions were found in the time course, extrapolation beyond stimuli, reliance on internalized expectations of the subjects, appeals on dynamic aspects of memory, leading Hubbard (1996) to proposition that both phenomena might be stemming from similar mechanisms or at least distinct facets of general displacement mechanism. On the other hand, Intraub (2002) suggested, that boundary extension and representational momentum are related in a more general sense, proposing that they reflect anticipatory representations of spatiotemporal information.

Framework proposed by DeLucia and Maladia (2006) explains that boundary extension is ascribed to the scene schema, reflecting expectations about scene beyond the boundaries, while representational momentum is related to the motion schema. Scene schema processes were responsible for global and spatial properties and also guide the integration of successive views. Motion schema processes are operating with the data about local and global changes in the scene and helps subject to anticipate changes in stimulus. Those mechanisms are not existing alone but together enable an observer to integrate consecutive view of the changing scene.

5.7.Attentional Selection and Focus

In the study of Mathews and Mackintosh (2004), impact of the emotional content of the scenes on boundary extension effect size was discovered. Even with emotionally less extreme picture sets, boundary extension was still related to the presented scene's emotional aspect. Authors also suggested that participants with higher levels of anxiety tend to be more focused on the central object of the scene. As a result of attention being disproportionately distributed towards the centre, less focus was allocated to the peripheral sections of the scene, leaving subjects with scenes perceived as smaller and reported more minor boundary extension. Even though it is not clear if measured boundary extension was proportionally the same, just for a smaller picture or if the boundary extension was actually decreased, attentional selection and focus proposal suggests opposite results than the perceptual schema model.

6. Presence

When experiencing a subjective sensation of *presence*, humans feel as if they are being present in the scene (Coelho et al., 2006). The current idea of *presence* originated from Marvin Minsky's term *telepresence* as a description of a feeling of being physically situated in a remote location when interacting with a system interface (Minsky, 1980; Witmer & Singer, 1998). Prefix *tele-* descends from the *teleoperations* – specific type of virtual reality (VR) used for mediating the interaction between a machine located in distant environments such as space using a human-like designed robot or a device moving simultaneously with the user while providing auditory and visual feedback (Loomis, 1992). *Telepresence* later narrows its meaning of the concept only to the presence linked to the actual teleoperations, and the term (*virtual*) *presence* is from then on used for describing a presence perceived in a virtual environment (Sheridan, 1992).

At the day of the publication of this thesis, the theoretical anchoring of the term *presence* was not completely clear, and multiple classifications were found across the papers. While some researchers use the terms *presence* and *immersion* interchangeably (Nilsson et al., 2016), some think of *immersion* as a necessary factor for being able to experience the presence altogether with the *involvement* (Coelho et al., 2006), others describe *presence* and *immersion* as related concepts where *presence* is a reaction to the *immersion* (Slater, 2003). For the purpose of this thesis and further description of the topic, *immersion* and *presence* will be classified as related yet different concepts following the approach of Coelho et al. (2006) and Slater (2003).

From the beginning, presence gained significant attention in the research of virtual reality and teleoperators (Fontaine, 1992) and, until this day, is treated as the central concept when doing research focused on human interaction and virtual reality (Coelho et al., 2006). When looking back, the first scientific studies consisted of researching and creating a method for *measuring* the presence, resulting in the compilation of multiple questionnaires.

The first questionnaire, *Experience Questionnaire* (EQ; Fontaine, 1992), was used by the author to measure the sense of presence in intercultural and international *in-person* encounters. To measure the presence in virtual reality, Witmer & Singer compiled

the *Presence Questionnaire* (PQ; Witmer & Singer, 1998), which is utilized in the experiments to this day in its third iteration (PQ; Witmer et al., 2005).

Presence is currently researched mostly in the relation to the education and training (Psozka, 2006) and gaming (Marto & Gonçalves, 2022). Connecting the presence to emotions (Ravaja et al., 2006), but also to performance. In research focused on simulation-based training, Stevens and Kincaid (2015) found out that the performance of participants who were highly present in the simulation was higher than the performance of participants with lower levels of presence.

6.1. Involvement

While some authors (McMahan, 2003) use the term involvement interchangeably with *engagement*, for the purpose of this thesis, first term *involvement* will be used. According to the Witmer and Singer (1992), *involvement* is a “psychological state experienced as a consequence of focusing one’s energy and attention on a coherent set of stimuli or meaningfully related activities and events” (p. 227). This state is dependent on the subjective perceived significance or meaning of the given stimuli. Authors also noted that involvement grows in connection to the growing attention towards stimuli, which ultimately leads to increased sense of presence.

Rothschild (1984) perceives the *involvement* as a continuous variable of a state of interest, motivation, or arousal where effort is a function of the involvement level. Level of involvement can be measured in context of the three areas – *enduring* (reflecting pre-existing relationship between individual and situation, values, previous experience with the object), *situational* (temporary changes in relevance towards the object) and *response* (combination of situational and enduring changing across the stages of decision making) involvement (Houston & Rothschild, 1978). Other researchers explored and described two dimensions of involvement – *importance* (how does the stimulus matter to the subject) and *interest* (emotional and value-related factor of the stimulus) (McQuarrie & Munson, 1992).

Involvement was researched long time before coining the term *presence*. In the advertisement field, involvement is well-established phenomenon when conducting a research of buyer’s behaviour (Brennan & Mavondo, 2000). Linked to learning process and advertisement, Krugman (1965) in his work on television and learning differentiated *low* and *high* involvement, both affecting the information processing and learning differently. Latter research conducted by Petty et al. (1992) confirmed that, involvement is a moderating factor for learning. High involvement participants showed higher rates of recognition and recall of the brand name than low involvement participants.

Nowadays, on top of the advertisement, involvement is mostly researched in relationship with gaming and virtual reality. Calleja (2007) describes the concept of involvement in relation to the gaming and proposed a digital game involvement model indicating that dimension of the involvement appear on two levels – micro and macro. On Macrolevel involvement is related to the motivation to play a game repeatedly and

microlevel relates to the involvement during the actual playing. Takatalo et al. (2010) proposed measuring model of the presence in gaming, utilizing the concepts of dimensions of involvement proposed by McQuarrie with Munson (1992) combined with concepts of physical and social presence.

6.2.Immersion

Two approaches towards immersion exist in the academic publications, those are not necessary mutually exclusive, but perhaps rather a different point of view on the topic. In the first one, researchers consider *immersion* being solely the description of technology, determined primarily by the parameters of used display. Those parameters are following how are the used displays *inclusive*, *extensive*, *surrounding*, and *vivid*. *Inclusiveness* is a measure of how much is physical reality suppressed, *extensiveness* stays for a range of accommodated sensory modalities, *surrounding* indicates how panoramic is the medium and *vividness* maps the display resolution, fidelity, and modalities such as colour resolution and overall focuses on the quality of display (Slater & Wilbur, 1997). Theories belonging to this approach put immersion to related, yet quite opposite relationship to *presence*, where *immersion* is strictly technological and objective, whereas *presence* is solely the description of the state of consciousness, feeling of being there.

Second stream of theories is defined less strictly, blurs the line of immersion more and works with the concept within a broader psychological context. Starting with the definition by Janet Murray (2016), *immersion* is more metaphorical term describing one's feeling of being emerged in water. Analogically, immersion as a psychological term delineating the sensation of being fully surrounded by other reality, which takes up the attention and perceptual apparatus. Even though still strongly connected to the perceived media, researchers tend to agree that absolute realism of the photo and audio contents is not necessary to experience sense of immersion. Similarly, to the first presented definition in this chapter, even this stream of researchers back the importance of the level of *surrounding*. Suggesting that the more is the technology used for presenting the virtual environment surrounding in matters of visual dimension and sound, the more immersive will the experience be, even though immersion is still possible even on the less surrounding smaller screens and devices (McMahan, 2003).

Types of immersion defined by Zhang et al. (2017) seems to follow the two points of view presented earlier in this chapter. Authors of the study defined *emotional* and *spatial* immersion, where *spatial* immersion is triggered by, as name suggests, spatial qualities of the virtual environment. Immersion is then achieved by manipulating compositions of the scene (e.g. changing the view by zoom-in and out, changing camera

angles) creating the illusion of bodily presence in the virtual environment. Term *emotional* immersion is reserved for the feeling of being emotionally aroused and absorbed by the consumed content. Although it does not provide the same sense of physical presence in the environment, *emotional* immersion enables subjects to empathize and feel connected with the watched story or characters.

Jennett et al. (2008) created an immersion measuring method focused mainly on the gaming experience, which is still being used in experiments until this day. Method is called *Immersive Experience Questionnaire* (IEQ) and consists of 33 questions based on the three surmountable levels of immersion. First level the authors call *engagement level*, which is achieved after the subject overcome the barrier of gamer preference (investing the time to learn how the game work). Followed by *engrossment level* achievable by overcoming barrier of game construction – usability and ability to control the game environment must be smooth, almost invisible, causing the subjects to stop being so aware about the real life surrounding them. Last level is the *total immersion*, where after overcoming the barriers of empathy and atmosphere, the detachment from the reality gets high, as well as sense of presence. To reach the total immersion, high level of attention is needed which makes it quite rare to achieve in comparison to the *engagement* and *engrossment*.

Interesting aspect of immersion is that sociocultural context changing the perception of what does mean to be immersive. In the 1990s as immersive environment would be considered one of the first 3D games running in resolution 320 x 160 px on small CRT monitor (Radianti et al., 2020). In comparison to current studies and narrative, when talking about immersive environment, more modern technology such as VR headsets is considered.

6.3.Effect of screen size on presence, immersion and scene memory

Although not many studies regarding the effect of screen size were published despite of growing interest in the topic (Detenber & Reeves, 1996), several suggesting a link between screen and image size and multiple phenomena that might directly or indirectly influence the boundary extension can be found. Due to boundary extension being a memory error, effect of image and scene size on remembering and attention seem to be especially relevant. However, screen size was also researched in relationship to the immersion and presence, which are connected to the learning and overall performance (Stevens & Kincaid, 2015) in tasks.

Recent study examined effect of the image size on ability to remember presented scenes. Naïve participants were instructed to observe sets of images using stimuli in two sizes (3° and 24°) without knowledge about upcoming recognition task. Bigger images were remembered better, with 20% higher accuracy than the smaller ones, memory was proportional to the image sizes (Masarwa et al., 2022).

Effect of screen size on attention has been suggested by authors of experiment (Reeves et al. (1992) as cited in Detenber and Reeves, 1996), where subjects observing faces on smaller and larger screens paid more attention to the presented stimuli.

Screen size effect on immersion has been suggested in the study by Rigby et al. (2016) in experiment focused on watching content on three different devices ranging from 4.5-inch mobile device to 13-inch laptop and finally to 30-inch monitor. When compared two larger screens, no differences in immersion have been found. However, reduced immersion was measured on the mobile condition. Smaller screen size also led to lower immersion rates in the experiment by Thompson et al. (2012), when comparing game experience on different size touchscreens. Even presence was linked to the screen size, in experiment where subjects watched movies on two different screens, again bigger screen led to higher subjective reported presence (Troscianko et al., 2012).

Over the years, several studies connecting the screen or stimuli size and cognitive concepts have emerged and even though rather sparse in the numbers, they suggest that screen size might affect the perceived stimuli and cognitive processes.

7. Current Experiment

The experiment presented in this thesis focuses on measuring the boundary extension and effect of screen size on this phenomenon. More specifically, if distinctively different screen sizes – on a computer and on a mobile device, will affect the boundary extension. Majority of boundary extension experimental settings utilized in previous studies are based on the presentation on computers (Dickinson & Intraub, 2008; Gagnier et al., 2013), some studies used printed media (Gottesman & Intraub, 2003) or projectors (Intraub & Berkowits, 1996; Intraub & Bodamer, 1993) – in all cases making the presented stimuli rather big. Exception for a smaller size of presented stimuli would be a study where influence of the aperture size on boundary extension was examined (Dickinson & Intraub, 2009), however, this study focused on cropping the picture to create a window-like look rather than focusing on making the whole stimuli proportionally smaller.

Previous studies focused on screen size already suggested its influence on several areas of cognitive psychology including the human attention (Reeves et al., 1999), memory (Masarwa et al., 2022; Reeves & Nass, 1996), immersion (Rigby et al., 2016) and presence (Troscianko et al., 2012).

Findings suggest, that with the growing screen size used for presenting a stimulus, subjects tend to remember the stimulus better, pay more attention and participate in cognitive tasks more effectively (Reeves et al., 1999). Attentional processes are necessary for the scene perception and memorising the scene, which is a key aspect for testing the boundary extension. This might affect not only the boundary extension, but also the confidence levels of subjects when completing the tasks. With growing popularity of the mobile devices over the desktop devices (Bröhl et al., 2018), I see a particular relevance of exploring this media for stimuli presentation.

The research question was formulated as follows:

Does the screen size affect the boundary extension?

To help to explore this research question, three hypotheses were stated:

H₁: Reported scene size will not match the actual presented photography.

H₂: On mobile devices, size of the measured boundary extension will be different from the measured boundary extension on desktop.

H₃: Measured confidence levels will be higher on the desktop device.

8. Method

In this chapter, methods used to conduct the experiment possibly answering research question and the hypotheses will be described. First describing the experimental group, continuing to procedure chosen and finishing with description of the stimuli before following up with the Ethics chapter.

8.1.Participants

Experimental group consisted of 75 students from Charles University who enlisted themselves in the pool of volunteers willing to participate in research under the auspices of Labels – Laboratory of Behavioural and Linguistic Studies. In exchange for participation in the experiment, students received points for completing a course requirement.

Sixty-one participants of the group identified as female, and only 14 participants identified as male; age ranged from minimum 18 years to a maximal 48 years ($M = 22.5$, $SD = 4.38$). All participants had corrected-to-normal ($n_{corrected} = 35$) or normal ($n_{normal} = 40$) vision.

8.2.Procedure

Participants were randomly assigned to four groups ($n_1 = 18$, $n_2 = 17$, $n_3 = 20$, $n_4 = 20$); each group differed in the stimuli data set (dataset A/dataset B) and order of tested devices (mobile first/desktop first) to eliminate a chance to influence the results with the order of the devices and to ensure that different dataset is used for each device condition (mobile, desktop) to avoid the presentation of the same stimuli twice.

	Group 1	Group 2	Group 3	Group 4
First part	Mobile Dataset A	Mobile Dataset B	Desktop Dataset A	Desktop Dataset B
Second part	Desktop Dataset B	Desktop Dataset A	Mobile Dataset B	Mobile Dataset A

Table 1. Distribution into groups.

Most participants were examined in groups of two, and a minority were examined alone. After being seated at the table, they were informed about and asked to sign in the informed consent with the participation in the experiment (Appendix A). After providing their consent, participants were informed after anonymisation of the experimental data and were asked to fill in the form tracking their age, sex and information about eye health and correction (Appendix B).

Once finished with the form, instructions were read to the participants, and they were provided with the written version of the instructions as well (Appendix C). Following a given time to go through the instructions, space for questions about the experiment was provided. When the administrator of the test was sure that the instructions were clear and understood, the procedure started.

Each experiment was split into two parts naturally by the device switch with up to a two-minute break created by a buffer needed for all participants to finish their test run without interfering with their concentration. Experiment on desktop and experiment on a mobile device shared the procedure, which is described below. Each part had one experimental round and eight testing rounds, totalling sixteen testing rounds per person. Experimental procedure was scripted in the jsPsych framework and ran on the Jatos server.

All displays of the trial were presented on a black background filling in the rest of the mobile device screen or a computer monitor. At the beginning of the procedure, brief instructions were displayed on the screen, as well as a button for starting the practice trial. After the trial, subjects needed to trigger the start of the actual experimental round manually, giving enough time to prepare for the experimental trials. At the beginning of each trial, a white fixation cross was displayed for 500 ms. The fixation was immediately followed by three randomly picked images from a stimuli pool A or B presented subsequently, each for 3000 ms. Scheme of this procedure is displayed in the Figure 5.



Figure 5. Example of the presented stimuli, each displayed for 3000 ms. Each of the stimuli was on the black background filling the rest of the screen.

After the last of the three stimuli presentation time ended, a randomly picked visual mask was displayed for 500 ms accompanied by the 1000 ms gap consisting of a black empty screen only. On the following display, there was one of the three previously presented images (Figure 6). In both the memorisation and recollection part, participants were presented with and wide-angle or close-up picture, creating a total of four combinations: close-up – close-up (CC), close-up – wide-angle (CW), wide-angle – wide-angle (WW) or wide-angle – close-up (WC). Those four conditions were randomly ordered throughout the specific experimental part, each repeating twice.

Underneath the response stimuli, the question “In comparison with the photograph presented previously, this one seems to be:” and 5-point Likert scale: 2 “Much farther-away”, 1 “Bit farther-away”, 0 “The same”, -1 “Bit closer-up”, -2 “Much closer-up” were located. Participants had unlimited time to answer the question.

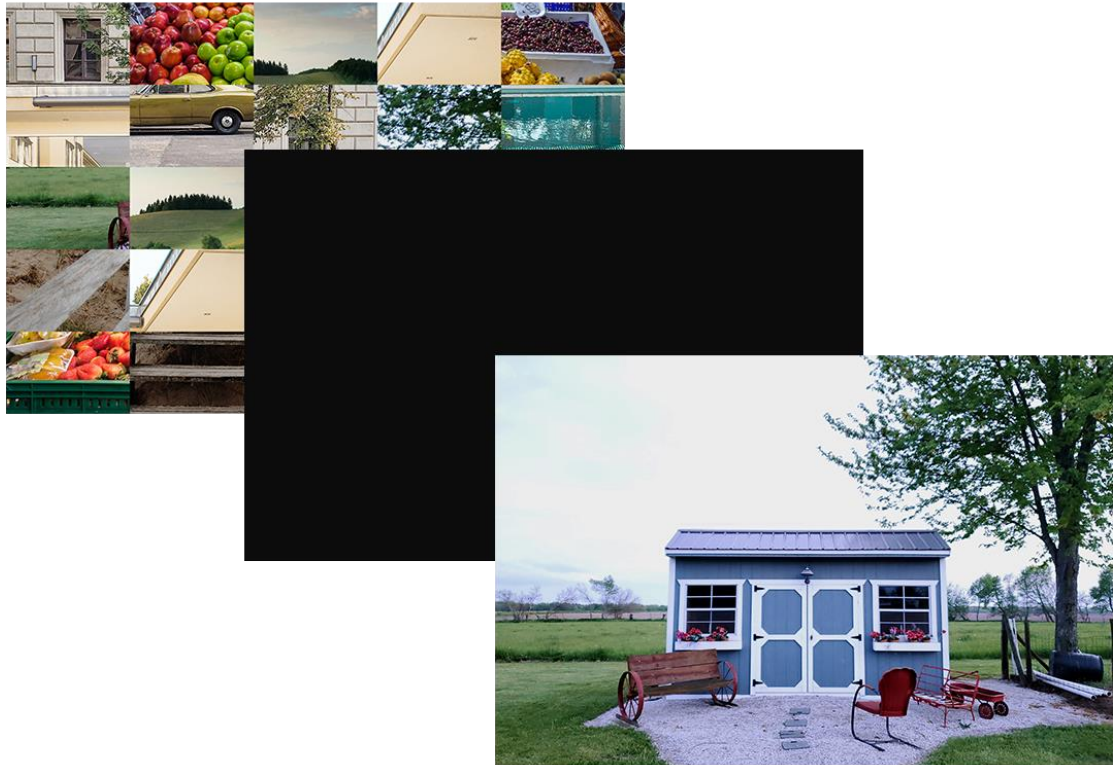


Figure 6. Visual mask presented for 500 ms, followed by 1000 ms empty screen and randomly picked stimulus from previously presented ones.

Once the participants picked an option, last part of the trial was displayed, this time a scale mapping the *confidence level*. Participants were asked: “*How sure am I about the answer*” with three options: 0 “*Not sure*”, 1 “*Somewhat sure*”, and 2 “*Very sure*”. Again, no time limit for the answer was set. For extra clarity, scheme of a trial is presented below in the Figure 7. When both participants finished all eight experimental trials on one device, they were given the complementary device and were asked to repeat the procedure on it.

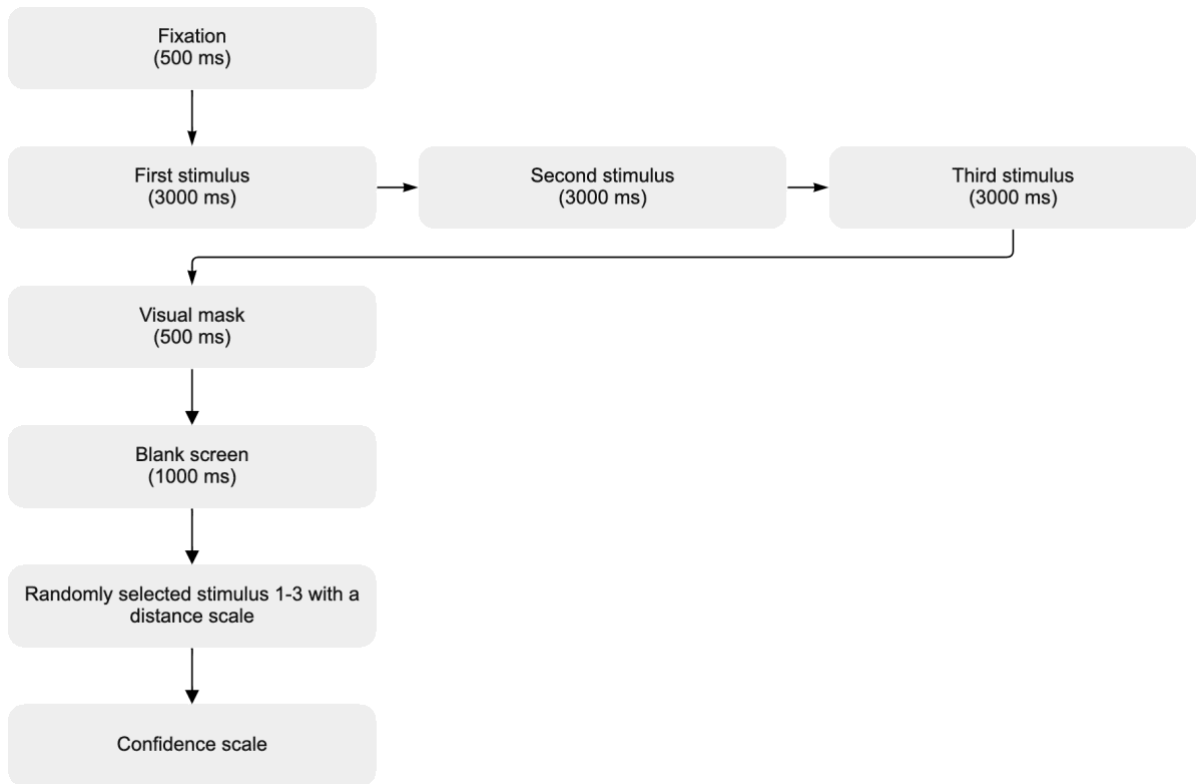


Figure 7. Scheme of the trial.

8.3.Stimuli

Sixty-eight images of different real-world scenes were gathered for the experiment, 38 images were downloaded from the public domain library, 30 images were photographed by the author of the study. Extra six images were sourced in the public domain library for the practice round, those images were not further utilized in the experimental trials. Each of the 74 stimuli was used in two variants: wide-angle (original photograph) and a close-up (original photograph enlarged by 15% and then cropped to the original size).

Used images varied in the content; however, all of them were of a rather neutral character, mostly depicting scenes of nature, cities, rooms, or multiple positioned items. Set of photographs combined single object and multiple object scenes, urban and natural scenes as well as pictures of closed spaces such as different rooms and open spaces such as wide streets and nature sceneries.

Selected images were neutral in the object distances as well; macro photographs and panorama photographs were avoided as well as images with an object cut off on one or more sides. All distracting texts on the images were edited out to reduce the possibility of subjects focusing on them. Images were 650 x 433 px for the mobile device, and for the desktop, 1200 x 800 px. Images were split into sets of 34 and 34 to ensure the presentation of different data sets for respective parts of the experiment and were randomised to prevent inter-trial repetition for each procedure. Each participant thus seen every stimulus only once in the whole experiment.

Fourteen static visual masks were prepared for the experiment, consisting of combined twenty-five cut-outs of the used images to create a grid. Twelve masks were split into two sets evenly and presented in the same size as test stimuli and two masks were used for the practice round. Example of used mask is presented in Figure 8.

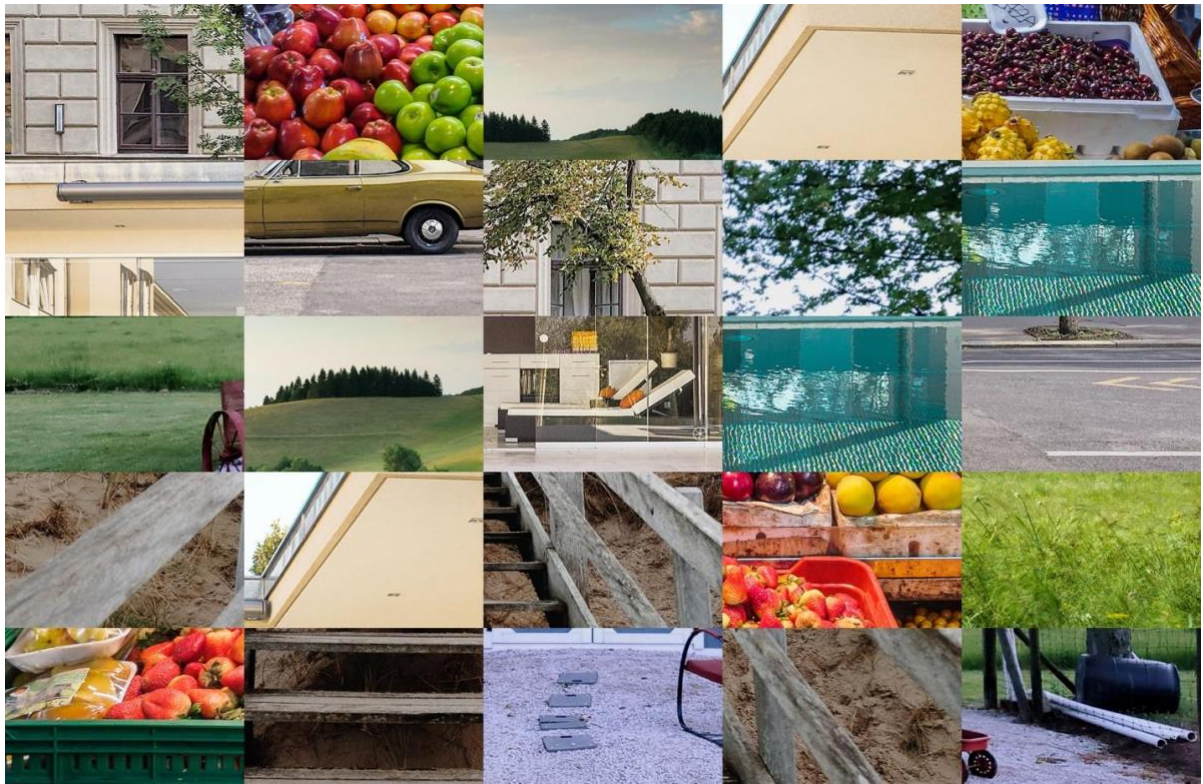


Figure 8. Example of a visual mask.

8.4.Apparatus

Used desktop device was a HP Pro 3500 series computer with a connected 24" Philips monitor display (1920 x 1080 px, 32bit colour, 60Hz) with procedure presented in a full screen mode. Brightness of the display was set to maximum. Participants used a mouse to select a value on the BE and confidence scales.

iPhone X (resolution 2436 x 1125 px, 458 ppi) was used as a mobile device, with dark mode activated to reduce distractions from the visible address bar and brightness set to maximum. Mobile device was held in the portrait mode.

Participants were separated from each other by a small partition wall. No tools were used for ensuring a constant distance between the participant and the devices.

9. Ethics

Participation on the experiment was entirely voluntary. Each participant signed informed consent (Appendix A) containing information about possibility of withdrawing from the experiment, data handling and possibilities to meet the eventual requirements of possible signed in a course if they do not want to participate in the specific experiment. The procedure was not more physically or mentally demanding than everyday computer work. Participants could leave at any point of the experiment without stating the reason as well as they could ask questions during the experiment.

Due to the study being of a memory-based character, sensitive data were not gathered. Data from the questionnaire were anonymised and paired with the results of the trials by a six-digit code which was not at any point paired to the name of the participant. Raw data were not distributed outside of the research team. Processed questionnaires and experimental data were safely stored.

10. Data analysis

Statistical data analysis was carried out in Jamovi 2.0.0.0 (The jamovi project, 2021) using the module GAMLj (Gallucci, 2019), data were transformed in MS Excel 16.6.31 (Microsoft Corporation, 2022). All analyses were performed at a significance level of $\alpha = 0.05$.

At the beginning of the exploration of research question: “Does the screen size affect the boundary extension?”, descriptive analysis of the research sample was performed. Results of the descriptive analysis are presented in the subsection Participants.

Descriptive statistics and one-sample t-tests were used to investigate presence of the boundary extension in the dataset. To investigate the relationship of screen size to boundary extension and confidence scales, a linear mixed model was chosen due to the ability to select random effects and fixed effects and thus separately examine each variable accordingly to the stated hypotheses. For both scales, two datasets were prepared anticipating the – first containing data of CC and WW trials, second only containing data of CW and WC trials. CW and WC conditions are in their ratings opposite to each other, to analyse them together, CW data were reversed since both conditions. This was made possible by both variables being measured in the same way – as difference from the correct answer.

11. Results

In this chapter, data analysis results of variables related to the hypothesis will be described. First, descriptive analysis of the perceived stimuli size and confidence scales will be presented. In following subsection results of the linear mixed model for both CC/WW and CW/WC conditions will be presented. Last section will repeat the linear models using the data of participants only scoring on the confidence level scale higher than 0 (“not sure”). Data from the practice rounds are not included in the data analysis.

11.1. Descriptive statistics

All 1200 trials were completed successfully, 600 trials for mobile device and 600 trials for desktop device were obtained.

To determine possible presence of boundary extension for the participant, difference between actual size of the photography and reported size of the photography on the used -2 to 2 scale can be compared. For CC and WW conditions, reported value on the BE scale should be 0 “The same”. By reporting negative values (-2) “Much closer-up” or (-1) “Bit closer-up”, boundary extension would be indicated, whereas positive values (1) “Bit farther-away” or (2) “Much farther-away” would indicate the boundary restriction. CW condition would be assessed in a similar manner; however, the correct reported value should be (2) “Much father-away” and WC condition (-2) “Much closer-up”. Written overview of the results can be found in Table 3, visual overview in the graph below (Figure 9).

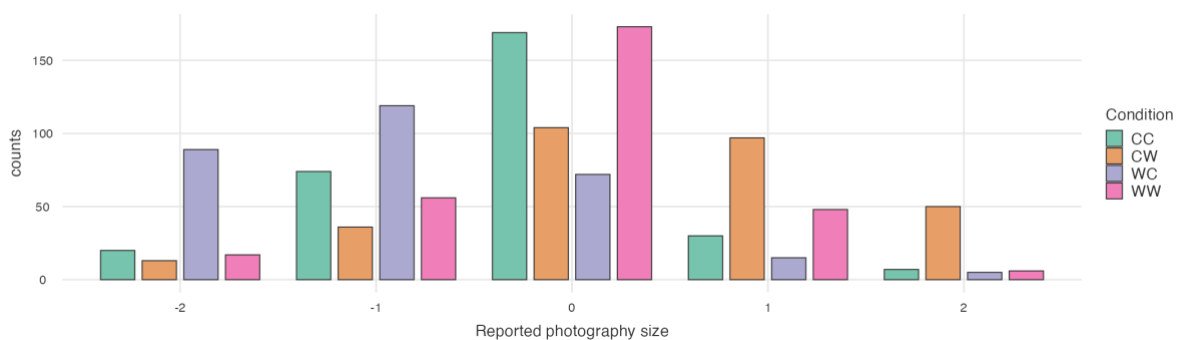


Figure 9. Graph of reported photo size for all possible orders of presented stimulus sizes.

Starting with the close-up presented stimuli and close-up stimuli in the recognition part of the trial (CC), majority of the trials were responded correctly, specifically in 169 cases (56%). In 37 cases (12.33%) pointing towards boundary restriction and in 94 cases (31.33%) towards boundary extension. For the WW condition 173 (57.66%) cases were responded correctly not resulting in any memory error. 54 (18%) cases would suggest boundary restriction and 73 (24.33%) observations boundary extension.

Close-up presented stimuli followed by the wide-angle stimuli (CW) trials were responded correctly (2; “Much father-away”) in 50 cases (16.66%). All other options on the scale are pointing towards boundary restriction, totalling in 250 trials (83.33%). Most often subjects reported the photograph to be either (0) “The same”, specifically in 104 cases (34.66%) or the (1) “Bit father-away” – in 97 (32.33%) cases.

Responses gathered in the WC condition were almost reverse to the CW condition. Correct answer for this condition trials was (-2) “Much closer-up” and was picked in 89 cases (29.66%). With other options suggesting boundary extension in 211 (70.33%) trials total, (1) “Bit closer-up” was the most selected, in 119 cases (39.66%), followed by the (0) “The same” reported 72 times (24%).

	Much father-away (2)	Bit father-away (1)	The same (0)	Bit closer-up (-1)	Much closer-up (-2)
CC	7	30	169	74	20
WW	6	48	173	56	17
CW	50	97	104	36	13
WC	5	15	72	119	89

Table 3. Measured photography size responses for all conditions. Correct answers are in bold.

Means of confidence levels and reported image sizes for each condition were examined first for the whole data set (Table 4) and then divided by device condition to two groups consisting of mobile only and desktop only data (Table 5).

Condition	N	BE mean	BE SD	Confidence mean	Confidence SD
CC	300	-.23	.81	1.06	.74
WW	300	-.10	.80	1.10	.72
CW	300	.45	1.04	1.18	.76
WC	300	-.91	.94	1.25	.71

Table 4. Means and standard deviations of boundary extension and confidence scales for each of the conditions for the whole dataset.

Device	Condition	N	BE mean	BE SD	Confidence mean	Confidence SD
Mobile	CC	150	-.23	.83	1.08	.72
Mobile	WW	150	-.07	.84	1.08	.69
Mobile	CW	150	.52	1.01	1.10	.73
Mobile	WC	150	-.89	.95	1.23	.71
Desktop	CC	150	-.23	.79	1.04	.76
Desktop	WW	150	-.13	.77	1.13	.75
Desktop	CW	150	.38	1.07	1.25	.73
Desktop	WC	150	-.92	.93	1.27	.70

Table 5. Means and standard deviations of confidence and boundary extension scales for all four conditions divided for mobile and desktop subset.

Following on the descriptive statistics of the dataset, to determine if the whole sourced dataset elicited significant boundary extension, set of four (for each condition CC/WW/CW/WC) one-sample t-test was conducted (criteria = 0).

Starting with the CC ($M = -.23, SD = .81$) and WW ($M = -.10, SD = .80$) trials showing two identical photographs in a row were negative from zero, indicating that stimuli presented in recognition trial were appearing more closer-up than the previously presented stimuli. For WW condition ($t(299) = -2.16, p = .03, d = .12$) suggesting low effect size and for the CC condition ($t(299) = -5.00, p < 0.001, d = .29$) as well.

In absolute values CW ($M = .45$, $SD = 1.04$) were closer to zero than WC ($M = -.91$, $SD = .94$) trials. CW condition ($t(299) = -7.48$, $p < .001$, $d = .43$) suggesting small to medium effect size and WC condition ($t(299) = -16.7$, $p < .001$, $d = .97$) rather big effect size.

Subject's confidence about picking the correct answer in boundary extension trial was measured on a 3-point Likert scale. Subjects chose (0) "Not sure" in 241 cases (20.08%), (1) "Somewhat sure" 540 times (45%) and (2) "Sure" 419 times (34.92%).

11.2. Mixed model results

To explore the collected data, multiple linear mixed models were prepared. Each subset used for the model contained 600 observations, 300 from mobile device and 300 from desktop device. For all linear mixed models, visual inspection of residual plots did not reveal deviation from the normality. Satterthwaite's method was applied to estimate degrees of freedom and to generate p-values.

11.2.1. Linear mixed model – Boundary extension

First, linear mixed model for subset of trials where presented stimuli did not change in the recognition part of the trial (WW and CC condition) was created. Boundary extension scale was used as the dependent variable, Device as fixed factor, Stimuli and Participant ID served as random factors. Overall model was not significant $F(1, 41) = .19$, $p = .66$. Fixed effect parameter estimates are reported in Table 6. Lack of difference between mobile and desktop devices is demonstrated on the graph below (Figure 10).

				95% Confidence Interval				
Names	Effect	Estimate	SE	Lower	Upper	df	t	p
(Intercept)	(Intercept)	-.17	.05	-.27	-.08	63.2	-3.73	< .001
Device1	PC - Mobile	-.03	.07	-.17	.11	41.0	.36	.66

Table 6. Fixed effects parameter estimates for the CC/WW subset.

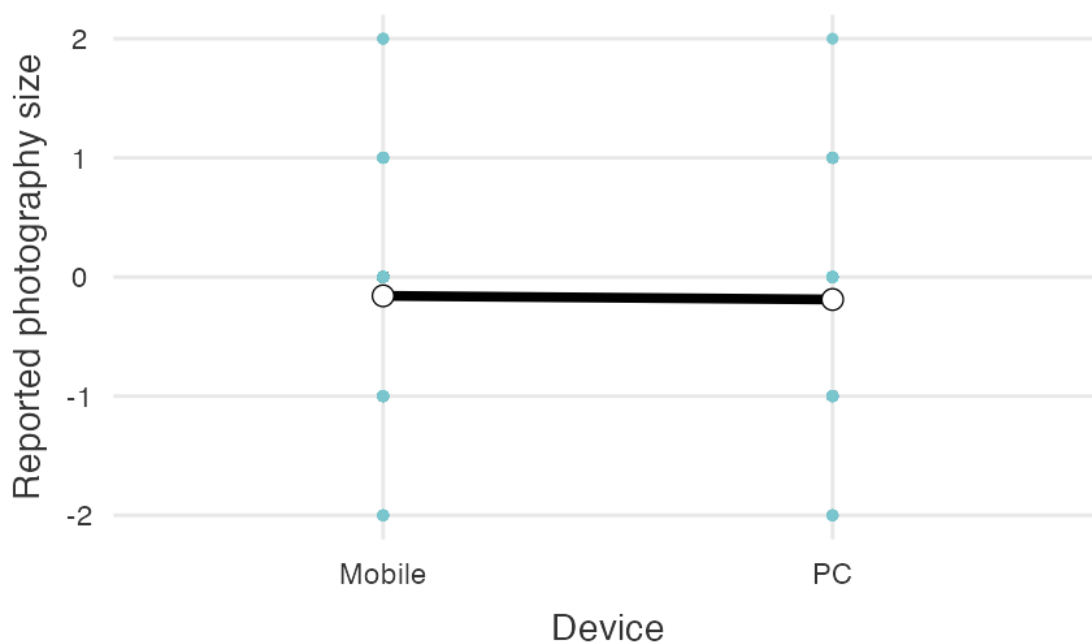


Figure 10. Effect plot for the Device variable, CC/WW subset.

Same process was done for the CW and WC condition subset. BE scale was used as a dependent variable once more, reversing the WC scores to measure the difference from correct answer for both conditions at the same time. Dependent variable was again the Boundary extension scale, device as a fixed factor and Stimuli with Participant ID were random factors. Neither in this case the model was not significant $F(1, 68.9) = .15, p = .70$. Fixed effect parameter estimates are reported in the Table 7, effect plot graph is reported in the Figure 11.

				95% Confidence Interval				
Names	Effect	Estimate	SE	Lower	Upper	df	t	p
(Intercept)	(Intercept)	-.68	.05	-.78	-.59	52.7	-13.68	< .001
Device1	PC - Mobile	.33	.09	-.14	.20	68.9	.38	.70

Table 7. Fixed effects parameter estimates for the CW/WC subset.

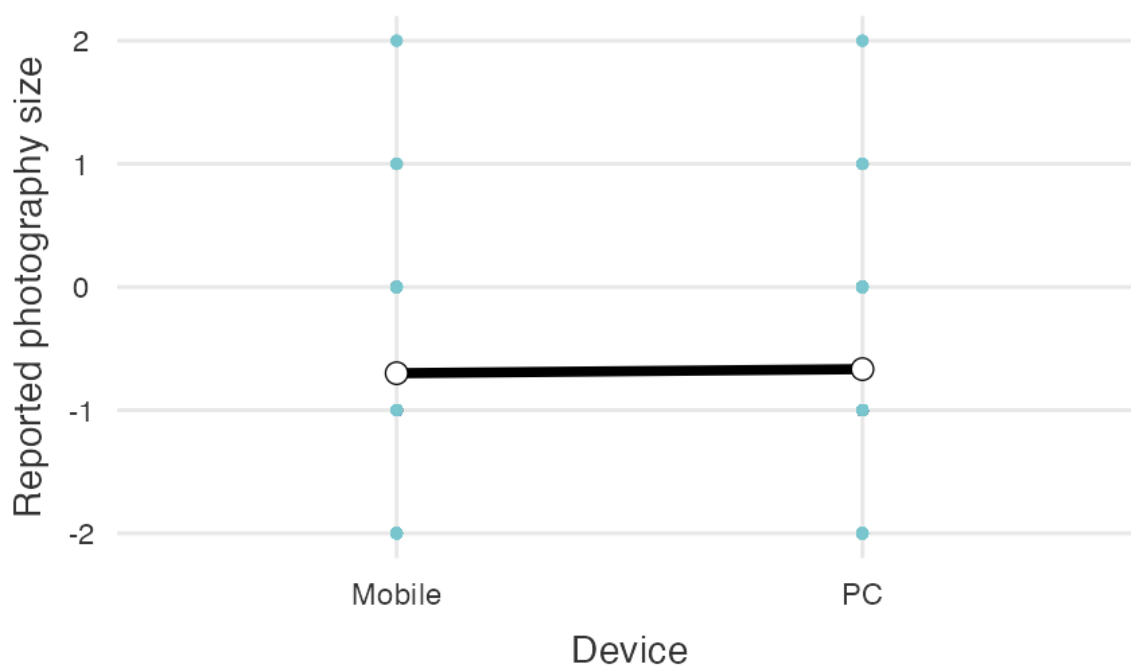


Figure 11. Effect plot for the Device variable, CW/WC subset.

11.2.2. Linear mixed model – Confidence

Similar procedure was used to build the linear mixed model for the confidence scale. Two subsets were analysed separately, first for the CC and WW conditions, second for the CW and WC conditions. Confidence scale served as dependent variable, Device as fixed factor and Participant ID and Stimuli were used as random factors. Model was not significant $F(1, 513) = .07, p = .79$ even in this case. Details about the fixed effect parameter are reported in Table 8, followed by an effect plot (Figure 12) below.

				95% Confidence Interval				
Names	Effect	Estimate	SE	Lower	Upper	df	t	p
(Intercept)	(Intercept)	1.08	.05	.98	1.17	73.1	22.21	< .001
Device1	PC - Mobile	.01	.05	-.91	.12	512.9	.26	.79

Table 8. Fixed effects parameter (Device) estimates for the CC/WW subset.

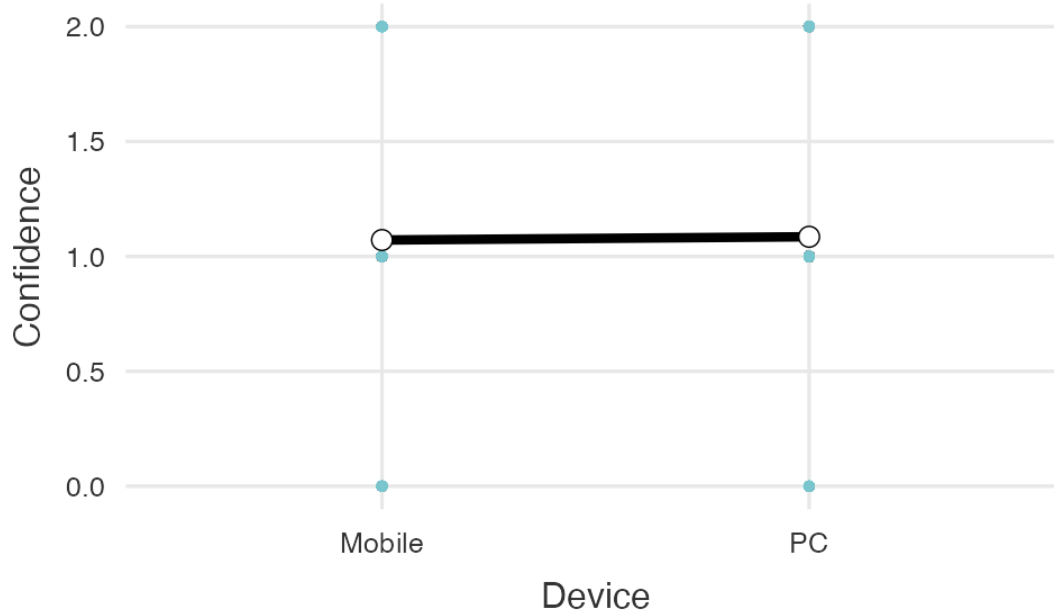


Figure 12. Effect plot for the Device variable, CC/WW subset.

To find relationship between device type and confidence with answer, model for CW/WC subset was prepared in the same manner as model for CC/WW subset. Using Confidence scale as dependent variable, Device as fixed factor and Participant ID together with Stimuli as random factors, model was not significant. However, stronger relationship in comparison to other models was found ($F(1, 522) = 3.16, p = .08$) pointing towards desktop devices yielding slightly higher confidence ratings. Details of the fixed effect parameter for Device are reported in the Table 9, effect plot graph is reported as Figure 13.

				95% Confidence Interval				
Names	Effect	Estimate	SE	Lower	Upper	df	t	p
(Intercept)	(Intercept)	1.21	.04	1.14	1.29	55.4	32.89	< .001
Device1	PC - Mobile	.10	.06	-.01	.21	522.1	1.78	.08

Table 9. Fixed effects parameter (Device) estimates for the CW/WC subset.

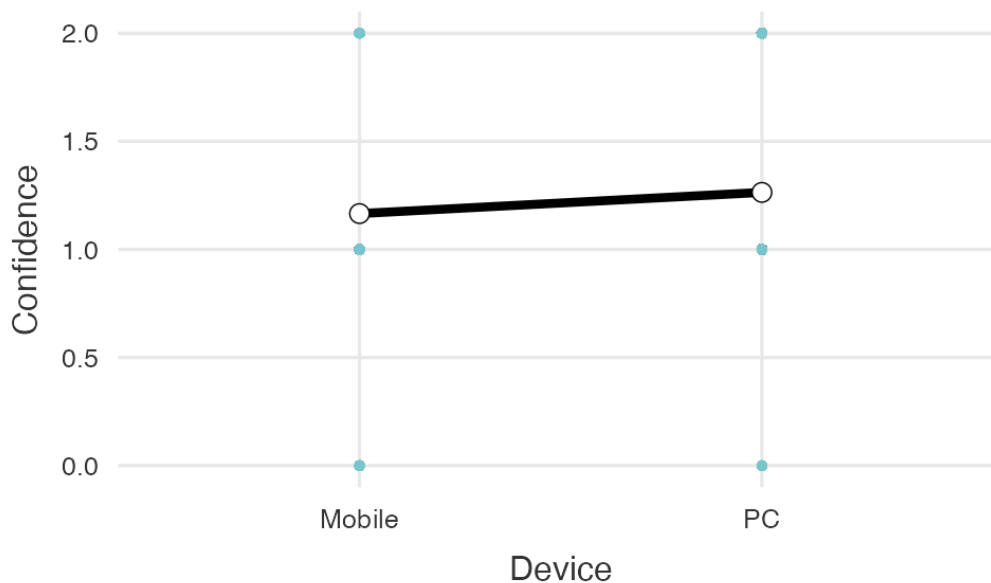


Figure 13. Effect plot for the Device variable, CW/WC subset.

11.2.3. Linear mixed model – Boundary Extension positive confidence subset

Last set of linear models was built with data filtered by confidence levels from the primary data set. Only data from trials with confidence levels above zero were used, filtering out the trials where participants rated their answer as “Not sure”. CC/WW subset consisted of 464 observations and CW/WC model consisted of 495 observations. Separating the CC/WW and CW/WC conditions again, two subsets were created. Models were then built in identical ways as the first model for Boundary extension.

Model using Confidence CC/WW subset was less significant ($F(1, 65.3) = .03, p = .86$) than the model using all CC/WW trials reported before.

				95% Confidence Interval				
Names	Effect	Estimate	SE	Lower	Upper	df	t	p
(Intercept)	(Intercept)	-.18	.05	-.28	-.08	62.8	-3.53	< .001
Device1	PC - Mobile	-.01	.07	-.13	.14	50.1	.06	.86

Table 10. Fixed effects parameter (Device) for CC/WW data with filtered out low confidence level.

Similar outcome was observed for the Confidence CW/WC subset mixed model, which was again less significant ($F(1, 73.2) = .38, p = .84$) than the model using all CW/WC trials.

				95% Confidence Interval				
Names	Effect	Estimate	SE	Lower	Upper	df	t	p
(Intercept)	(Intercept)	-.77	.06	-.88	-.66	56.5	-13.37	< .001
Device1	PC - Mobile	.02	.09	-.16	.20	73.2	.20	.84

Table 11. Fixed effects parameter (Device) for CW/WC data with filtered out low confidence level.

Overview of responses to the hypothesis and research question concludes this chapter as follows:

H₁: Reported scene size will not match the actual presented photography.

Based on results of the one-sample t-tests for each condition, CC ($M = -.23$, $SD = .81$) and WW ($M = -.10$, $SD = .80$) condition trials differed from zero, indicating presence of boundary extension. For WW $t(299) = -2.16$, $p = .03$. $d = .12$ and for CC $t(299) = -5.00$, $p < 0.001$, $d = .29$.

T-tests for CW ($M = .45$, $SD = 1.04$) and WC ($M = -.91$, $SD = .94$) conditions suggested that participants noticed the change in the presented pictures but reports still did not match the actual presented photography in all cases. For CW condition $t(299) = -7.48$, $p < .001$, $d = .43$, for WC $t(299) = -16.7$, $p < .001$, $d = .97$.

Across all conditions, responses differed from the actual presented photography and thus **H₁ is accepted.**

H₂: On mobile devices, size of the measured boundary extension will be different from the measured boundary extension on desktop.

Based on the data from mixed models and sourced experimental data, mobile devices and desktop devices did not differ in yielded boundary extension.

Mixed model exploring effect of device on boundary extension for CC/WW subset was not significant $F(1, 41) = .19$, $p = .66$, as well as the same model for CW/WC subset $F(1, 68.9) = .15$, $p = .70$. Results did not differ markedly even for the CC/WW and CW/WC subsets with low confidence levels filtered out. With CC/WW positive confidence subset model for effect of device on boundary extension not being significant ($F(1, 65.3) = .03$, $p = .86$) and similarly the same model using CW/WC positive confidence subset ($F(1, 73.2) = .38$, $p = .84$).

No significant effects were measured across the four mixed models, thus H₂ cannot be accepted, and **null hypothesis is accepted** instead.

H₃: Measured confidence levels will be higher on the desktop device.

Relationship between confidence level and device type was not significant $F(1, 513) = .07, p = .79$. Even though most significant model of this study was detected when exploring the CW/WC subset ($F(1, 522) = 3.16, p = .08$) it did not reach the required significance level of $p < .05$.

To conclude, H₃ is rejected, and **null hypothesis is accepted** instead.

Does the screen size affect the boundary extension?

From responses gathered in this data analysis, significant relationship between used screen sizes and boundary extension could not be proven and rather leading to further questions and ideas, which will be discussed in the following chapter.

12. Discussion

This thesis was focused on the boundary extension and differences in yielded effect caused by presenting stimuli on smaller and bigger screens. Aiming to describe new possible aspects affecting the boundary extension, experiment where each participant finished set of trials on both devices was conducted and data was later compared.

When observing the descriptive data, possible boundary extension was measured in 31.5% of all trials, no effect detected in 40.08% trials and boundary restriction detected in 28.42% of trials. The experimental results show a similar trend in the distribution of individual memory errors relative to correctly answered trials, but the overall percentages of correct answers are lower. To put in perspective, Ménétrier and Didierjean (2013) presented similar experiment, where 44% responses were correct, 33% showed boundary extension and 23% showed boundary restriction. However, when comparing only CC and WW of non-inverted images in Intraub and Berkowits (1996), results in this thesis experiment are less appealing. Intraub reported images being reported as closer-up in 53%, same in 42% and farther in 5%, whereas this study for CC and WW condition reached the “closer-up” response in only 27.83%, “same” in 57% and “farther-away” in 15.16%. Stimuli used in Intraub and Berkowits (1996) consisted just of photographs of single object in centre against a background which is different from the stimuli set presented in this experiment, which is common especially for early BE experiments. Even though this thesis stimuli contained some several pictures imitating this scene structure, majority of used stimuli had more structured backgrounds, more objects presented on a scene, which might account at least partially for the differences.

Overall boundary extension evidence is not as strong as reported in previous studies. Exact comparison being close to impossible with majority of studies utilizing other experimental schemas, which were either good stimuli match to stimuli in experiment presented in the thesis or having similar sequence of stimuli or having similar presentation times, but never all of them.

When comparing to the Mamus and Boduroglu (2017), with longer presentation times (15 s) and recognition-oriented trial, boundary extension effect was strong when comparing to experiment presented in this thesis. Mamus and Boduroglu (2017) found higher levels of boundary extension taking place, WW ($M = -.16, SD = .36$) and the CC ($M = -.43, SD = .38$) with WW condition $t(72) = -3.88, p < .001, d = .44$ and CC condition $t(72) = -9.57, p < .001, d = 1.13$. Results presented in this thesis experiment not only had lower means differing from the zero, but also lower size effects suggesting weaker measured evidence.

Although the means differed less strongly than in different studies, WW and CC boundary extensions measured in presented experiment followed the pattern consistent with perceptual schema, with WW being lower WW ($M = -.10, SD = .80$) than the the CC condition CC ($M = -.23, SD = .81$), suggesting that wide-angle images providing enough context and predictable area to the participant in contrast to the close-up images which leads to activation of other sources (Intraub et al., 1992).

When looking at the reported results (Table 5), responses “Bit farther away” for CW condition and “Bit closer-up” for the WC condition are higher than actual correct answer—raising a question if semantic differences in understanding of the individual scale items between participants could account at least partially for such ratings. In neither spoken nor written instructions were the scale items described, leaving them open for the subjects’ interpretation. In future experiment creating another group or trial where item rating would be performed by different method might answer this question.

Confidence rating of study presented in this thesis – “Not sure” – 20.08%, “Somewhat sure” – 45% and “Sure” – 34.92%, were lower than confidence levels reported by the control group in study by Munger and Multhaup (2016) who used similar experimental design – presenting 3 images in a row, each for 5 seconds, followed by a visual mask, boundary extension rating and confidence rating. In their study, participants

reported confidence followingly: “Not sure” 8%, “Pretty sure” 40% and “Sure” 52%. Authors of this study used narrower selection of stimuli, focusing only on pictures with one central object (such as picture of single piece of fruit) and multiple crop sizes of the close-up stimuli – 10%, 15% and 20%.

Experimental setup by Dickinson and Intraub (2008) using the similar trial schema (three stimuli followed by a mask and boundary rating), presenting the stimuli for shorter period of time (325ms) showed similar rates of the confidence with “Not sure” (20%) being almost the same as in this thesis (20.08%). Varying in the ratio of “Pretty sure” (57%) and “Sure” (21%) which was higher in favour of “Sure” (34.92%) in experiment presented in this thesis.

Differences between the device types were not confirmed in the presented experiment. Multiple contexts to this effect are available.

If screen size is connected to the memory as stated in previous study (Masarwa et al., 2022), our results might point to boundary extension not being fully dependent on the memory suggesting that boundary extension might be more related to the perceptual schema.

When considering experimental outcomes in the context of immersion, typically, immersion tends to be reported as higher on bigger screens (Rigby et al., 2016), pointing out that boundary extension might not be connected to the immersion. For further studies, utilizing the Immersive Experience Questionnaire might bring more robust evidence as well as fixing factors of the experimental procedures discussed below.

However, more accessible, and more straightforward explanation might exist – significant effects of device might have not been found based mainly on the environmental and experimental factors. Several limitations of the experiment must be considered. Sample which volunteered in the experiment was not representative for the whole population – majority of the participants were female university students in age ranging from 18 to 48 years ($M = 22.5$, $SD = 4.38$). Also, further refining of the testing process would be helpful in controlling distractions.

Starting with the devices itself; for experimental purposes mobile and desktop display was chosen, however better balance between two might have yielded different outcomes. On mobile device, screen with higher pixel density was used then on the desktop device, theoretically creating imbalance between used displays. Brightness of the

devices were set for both on maximum but was not match to each other as well as colour richness, thus different display factors besides the size might have played the role.

Stimuli were set to maximal possible size, but due to different screen aspect ratio of the screens, on mobile device picture photos took up proportionally more space than on a desktop. Due to the technical limitations, mobile device was displaying visible URL bar, where desktop device was not, adding a possible distractor on one of the devices. Also as stated earlier, stimuli contents might have played a role as well and thus for future experiments mapping the scene types more strictly might me a good addition.

Distance between participant and screen was not fixed in neither of the trials, although possible increasing ecological value by choosing perhaps most comfortable position for the respective participant, another factor that was unaccounted for.

In 1200 trials conducted in total, boundary extension was measured in 31.5% of the trials following a similar ratio of responses to other studies. Even so, it cannot be clearly and confidently stated that boundary extension is robust with respect to screen size due to the large number of limitations of this experiment. For future experiments, it would be helpful to secure the factors above to be able to confirm the robustness and resiliency of boundary extension to changes at different screen sizes.

13. Conclusion

The main focus of this thesis was to explore the effect of screen size on boundary extension. Even though being a robust phenomenon relatively stable occurring across age groups and presentation times, previous research showed multiple factors such as type of the presented stimuli or emotional content of the stimuli affecting the boundary extension.

In attempt to broaden the knowledge of factors influencing boundary extension, experiment was prepared. Two sets of trials for both devices were used resulting in boundary extension measured on both, but without a significant difference between the devices. Overall boundary extension ratings were lower than in previous studies suggesting that other factors might have played a role in measuring the differences between the devices. Repeating the experiment with more precision as described in the discussion would help to further explain the current findings.

Resources

- Bainbridge, W. A., Isola, P., & Oliva, A. (2013). The intrinsic memorability of face photographs. *Journal of Experimental Psychology: General*, *142*(4), 1323-1334. <https://doi.org/10.1037/a0033872>
- Bainbridge, W. A., & Baker, C. I. (2020). Boundaries Extend and Contract in Scene Memory Depending on Image Properties. *Current Biology*, *30*(3), 537-543.e3. <https://doi.org/10.1016/j.cub.2019.12.004>
- Beighley, S., & Intraub, H. (2016). Does inversion affect boundary extension for briefly-presented views?. *Visual Cognition*, *24*(3), 252-259. <https://doi.org/10.1080/13506285.2016.1229369>
- Beighley, S., Sacco, G. R., Bauer, L., Hayes, A. M., & Intraub, H. (2019). Remembering: Does the emotional content of a photograph affect boundary extension?. *Emotion*, *19*(4), 699-714. <https://doi.org/10.1037/emo0000477>
- Biederman, I. (1972). Perceiving Real-World Scenes. *Science*, *177*(4043), 77-80. <https://doi.org/10.1126/science.177.4043.77>
- Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, *94*(2), 115-147. <https://doi.org/10.1037/0033-295X.94.2.115>
- Biederman, I., Glass, A. L., & Stacy, E. W. (1973). Searching for objects in real-world scenes. *Journal of Experimental Psychology*, *97*(1), 22-27. <https://doi.org/10.1037/h0033776>
- Biederman, I., Mezzanotte, R. J., & Rabinowitz, J. C. (1982). Scene perception: Detecting and judging objects undergoing relational violations. *Cognitive Psychology*, *14*(2), 143-177. [https://doi.org/10.1016/0010-0285\(82\)90007-X](https://doi.org/10.1016/0010-0285(82)90007-X)
- Brady, T. F., Konkle, T., Alvarez, G. A., & Oliva, A. (2008). Visual long-term memory has a massive storage capacity for object details. *Proceedings of the National Academy of Sciences*, *105*(38), 14325-14329. <https://doi.org/10.1073/pnas.0803390105>
- Brennan, L., & Mavondo, F. (2000). Involvement: An unfinished story. *Proceedings of ANZMAZ*, 132-137.
- Bröhl, C., Rasche, P., Jablonski, J., Theis, S., Wille, M., & Mertens, A. (2018). Desktop PC, Tablet PC, or Smartphone? An Analysis of Use Preferences in Daily Activities for Different Technology Generations of a Worldwide Sample. *Human Aspects of IT for*

the Aged Population. Acceptance, Communication and Participation, 3-20.
https://doi.org/10.1007/978-3-319-92034-4_1

- Brouwer, A. -M., Franz, V. H., & Thornton, I. M. (2004). Representational momentum in perception and grasping: Translating versus transforming objects. *Journal of Vision*, 4(7). <https://doi.org/10.1167/4.7.5>
- Bylinskii, Z., Isola, P., Bainbridge, C., Torralba, A., & Oliva, A. (2015). Intrinsic and extrinsic effects on image memorability. *Vision Research*, 116, 165-178.
<https://doi.org/10.1016/j.visres.2015.03.005>
- Calleja, G. (2007). Revising immersion: A conceptual model for the analysis of digital game involvement. *In Proceedings of the DiGRA 2007 Conference*.
- Candel, I., Merckelbach, H., & Zandbergen, M. (2003). Boundary distortions for neutral and emotional pictures, 10(3), 691-695. <https://doi.org/10.3758/BF03196533>
- Candel, I., Merckelbach, H., Houben, K., & Vandyck, I. (2004). How Children Remember Neutral and Emotional Pictures: Boundary Extension in Children's Scene Memories. *The American Journal of Psychology*, 117(2).
<https://doi.org/10.2307/4149025>
- Castelhano, M., & Williams, C. (2021). *Elements of Scene Perception (Elements in Perception)*. Cambridge: Cambridge University Press.
doi:10.1017/9781108924092
- Chapman, P., Ropar, D., Mitchell, P., & Ackroyd, K. (2005). Understanding boundary extension: Normalization and extension errors in picture memory among adults and boys with and without Asperger's syndrome. *Visual Cognition*, 12(5), 1265-1290. <https://doi.org/10.1080/13506280444000508>
- Coelho, C., Tichon, J., Hine, T. J., Wallis, G., & Riva, G. (2006). Media presence and inner presence: the sense of presence in virtual reality technologies. *From communication to presence: Cognition, emotions and culture towards the ultimate communicative experience*, 11, 25-45.
- Curby, K. M., Glazek, K., & Gauthier, I. (2009). A visual short-term memory advantage for objects of expertise. *Journal of Experimental Psychology: Human Perception and Performance*, 35(1), 94-107. <https://doi.org/10.1037/0096-1523.35.1.94>

- Daniels, K. K., & Intraub, H. (2006). The shape of a view: Are rectilinear views necessary to elicit boundary extension?. *Visual Cognition*, 14(2), 129-149. <https://doi.org/10.1080/13506280500460563>
- De Luca, F., McCormick, C., Mullally, S. L., Intraub, H., Maguire, E. A., & Ciaramelli, E. (2018). Boundary extension is attenuated in patients with ventromedial prefrontal cortex damage. *Cortex*, 108, 1-12. <https://doi.org/10.1016/j.cortex.2018.07.00>
- DeLucia, P. R., & Maldia, M. M. (2006). Visual memory for moving scenes. *Quarterly Journal of Experimental Psychology*, 59(2), 340-360. <https://doi.org/10.1080/17470210500151444>
- Detenber, B. H., & Reeves, B. (1996). A Bio-Informational Theory of Emotion: Motion and Image Size Effects on Viewers. *Journal of Communication*, 46(3), 66-84. <https://doi.org/10.1111/j.1460-2466.1996.tb01489.x>
- Dickinson, C. A., & Intraub, H. (2008). Transsaccadic representation of layout: What is the time course of boundary extension?. *Journal of Experimental Psychology: Human Perception and Performance*, 34(3), 543-555. <https://doi.org/10.1037/0096-1523.34.3.543>
- Dickinson, C. A., & Intraub, H. (2009). Spatial asymmetries in viewing and remembering scenes: Consequences of an attentional bias?, 71(6), 1251-1262. <https://doi.org/10.3758/APP.71.6.1251>
- Dickinson, C. A., & LaCombe, D. C. (2014). Objects Influence the Shape of Remembered Views: Examining Global and Local Aspects of Boundary Extension. *Perception*, 43(8), 731-753. <https://doi.org/10.1068/p7631>
- Dimitrov, P., Lawlor, M., & Zucker, S. W. (2012). Distance Images and Intermediate-Level Vision. *Scale Space and Variational Methods in Computer Vision*, 653-664. https://doi.org/10.1007/978-3-642-24785-9_55
- Dunlop, H. (2010). Scene classification of images and video via semantic segmentation. *2010 IEEE Computer Society Conference on Computer Vision and Pattern Recognition - Workshops*, 72-79. <https://doi.org/10.1109/CVPRW.2010.5543746>
- Epstein, R. (2005). The cortical basis of visual scene processing. *Visual Cognition*, 12(6), 954-978. <https://doi.org/10.1080/13506280444000607>

- Erdem, E., & Erdem, A. (2013). Visual saliency estimation by nonlinearly integrating features using region covariances. *Journal of Vision, 13*(4), 11-11. <https://doi.org/10.1167/13.4.11>
- Fontaine, G. (1992). The Experience of a Sense of Presence in Intercultural and International Encounters. *Presence: Teleoperators and Virtual Environments, 1*(4), 482-490. <https://doi.org/10.1162/pres.1992.1.4.482>
- Freyd, J. J., & Finke, R. A. (1984). Representational momentum. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*(1), 126-132. <https://doi.org/10.1037/0278-7393.10.1.126>
- Friedman, A. (1979). Framing pictures: The role of knowledge in automatised encoding and memory for gist. *Journal of Experimental Psychology: General, 108*(3), 316-355. <https://doi.org/10.1037/0096-3445.108.3.316>
- Gallucci, M. (2019). *GAMLj: General analyses for linear models*. [jamovi module]. Retrieved from <https://gamlj.github.io/>.
- Gagnier, K. M., Intraub, H., Oliva, A., & Wolfe, J. M. (2011). Why does vantage point affect boundary extension?. *Visual Cognition, 19*(2), 234-257. <https://doi.org/10.1080/13506285.2010.520680>
- Gagnier, K. M., & Intraub, H. (2012). When less is more: Line drawings lead to greater boundary extension than do colour photographs. *Visual Cognition, 20*(7), 815-824. <https://doi.org/10.1080/13506285.2012.703705>
- Gagnier, K. M., Dickinson, C. A., & Intraub, H. (2013). Fixating picture boundaries does not eliminate boundary extension: Implications for scene representation. *Quarterly Journal of Experimental Psychology, 66*(11), 2161-2186. <https://doi.org/10.1080/17470218.2013.775595>
- Gandolfo, M., & Peelen, M. V. (2021). Predictive processing of scene layout depends on naturalistic depth of field. <https://doi.org/10.1101/2021.11.08.467670>
- Gong, M., Xuan, Y., Smart, L. J., & Olzak, L. A. (2018). The extraction of natural scene gist in visual crowding. *Scientific Reports, 8*(1). <https://doi.org/10.1038/s41598-018-32455-6>
- Gottesman, C., & Intraub, H. (2003). Constraints on spatial extrapolation in the mental representation of scenes: View-boundaries vs. object-boundaries. *Visual Cognition, 10*(7), 875-893. <https://doi.org/10.1080/13506280344000130>

- Greene, M. R. (2019). The information content of scene categories. In *Knowledge and Vision* (pp. 161-194). Elsevier. <https://doi.org/10.1016/bs.plm.2019.03.004>
- Greene, M., & Oliva, A. (2009). Recognition of natural scenes from global properties: Seeing the forest without representing the trees. *Cognitive Psychology*, 58(2), 137-176. <https://doi.org/10.1016/j.cogpsych.2008.06.001>
- Groen, I. I. A., Silson, E. H., & Baker, C. I. (2017). Contributions of low- and high-level properties to neural processing of visual scenes in the human brain. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 372(1714). <https://doi.org/10.1098/rstb.2016.0102>
- Haber, R. N. (1985). Toward a theory of the perceived spatial layout of scenes. *Computer Vision, Graphics, and Image Processing*, 31(3), 282-321. [https://doi.org/10.1016/0734-189X\(85\)90032-5](https://doi.org/10.1016/0734-189X(85)90032-5)
- Henderson, J. M. (1992). Object identification in context: The visual processing of natural scenes. *Canadian Journal of Psychology/Revue canadienne de psychologie*, 46(3), 319-341. <https://doi.org/10.1037/h0084325>
- Henderson, J. M., & Hollingworth, A. (1999). High-level Scene Perception. *Annual Review of Psychology*, 50(1), 243-271. <https://doi.org/10.1146/annurev.psych.50.1.243>
- Hochberg, J. (1978). *Perception* (2nd ed.). Prentice-Hall.
- Houston, M.J. and Rothschild, M.L. (1978). Conceptual and Methodological Perspectives on Involvement. In: Hunt, H.K., Ed., *Advances in Consumer Research* 5, Association for Consumer Research, Ann Arbor, 184-187.
- Hubbard, T. L. (1996). Displacement in depth: Representational momentum and boundary extension. *Psychological Research*, 59(1), 33-47. <https://doi.org/10.1007/BF00419832>
- Hubbard, T. L., Hutchison, J. L., & Courtney, J. R. (2010). Boundary extension: Findings and theories. *Quarterly Journal of Experimental Psychology*, 63(8), 1467-1494. <https://doi.org/10.1080/17470210903511236>
- Hutchison, J. L. (2007). *Boundary Extension in the Auditory Domain* [Doctoral Dissertation]. Texas Christian University.
- Hutchison, J. L., Hubbard, T. L., Ferrandino, B., Brigante, R., Wright, J. M., & Rypma, B. (2012). Auditory memory distortion for spoken prose. *Journal of Experimental*

- Psychology: Learning, Memory, and Cognition*, 38(6), 1469-1489.
<https://doi.org/10.1037/a0028464>
- Intraub, H. (2002). Anticipatory spatial representation of natural scenes: Momentum without movement?. *Visual Cognition*, 9(1-2), 93-119.
<https://doi.org/10.1080/13506280143000340>
- Intraub, H. (2004). Anticipatory spatial representation of 3D regions explored by sighted observers and a deaf-and-blind-observer. *Cognition*, 94(1), 19-37.
<https://doi.org/10.1016/j.cognition.2003.10.013>
- Intraub, H. (2012). Rethinking visual scene perception. *Wiley Interdisciplinary Reviews: Cognitive Science*, 3(1), 117-127. <https://doi.org/10.1002/wcs.149>
- Intraub, H., & Richardson, M. (1989). Wide-angle memories of close-up scenes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 15(2), 179-187.
<https://doi.org/10.1037/0278-7393.15.2.179>
- Intraub, H., Bender, R. S., & Mangels, J. A. (1992). Looking at pictures but remembering scenes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18(1), 180-191. <https://doi.org/10.1037/0278-7393.18.1.180>
- Intraub, H., & Bodamer, J. L. (1993). Boundary extension: Fundamental aspect of pictorial representation or encoding artifact?. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 19(6), 1387-1397. <https://doi.org/10.1037/0278-7393.19.6.1387>
- Intraub, H., & Berkowitz, D. (1996). Beyond the Edges of a Picture. *The American Journal of Psychology*, 109(4). <https://doi.org/10.2307/1423396>
- Intraub, H., Gottesman, C. V., Willey, E. V., & Zuk, I. J. (1996). Boundary Extension for Briefly Glimpsed Photographs: Do Common Perceptual Processes Result in Unexpected Memory Distortions?. *Journal of Memory and Language*, 35(2), 118-134. <https://doi.org/10.1006/jmla.1996.0007>
- Intraub, H., Gottesman, C. V., & Bills, A. J. (1998). Effects of perceiving and imagining scenes on memory for pictures. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 24(1), 186-201. <https://doi.org/10.1037/0278-7393.24.1.186>
- Intraub, H., Hoffman, J. E., Wetherhold, C. J., & Stoehs, S. -A. (2006). More than meets the eye: The effect of planned fixations on scene representation, 68(5), 759-769.
<https://doi.org/10.3758/BF03193699>

- Intraub, H., & Dickinson, C. A. (2008). False Memory 1/20th of a Second Later. *Psychological Science*, *19*(10), 1007-1014. <https://doi.org/10.1111/j.1467-9280.2008.02192.x>
- Intraub, H., Morelli, F., & Gagnier, K. M. (2015). Visual, haptic and bimodal scene perception: Evidence for a unitary representation. *Cognition*, *138*, 132-147. <https://doi.org/10.1016/j.cognition.2015.01.010>
- Irwin, D. E. (1996). Integrating Information Across Saccadic Eye Movements. *Current Directions in Psychological Science*, *5*(3), 94-100. <https://doi.org/10.1111/1467-8721.ep10772833>
- Isola, P., Xiao, J., Torralba, A., & Oliva, A. (2011). What makes an image memorable?. *CVPR 2011*, 145-152. <https://doi.org/10.1109/CVPR.2011.5995721>
- Jennett, C., Cox, A. L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T., & Walton, A. (2008). Measuring and defining the experience of immersion in games. *International Journal of Human-Computer Studies*, *66*(9), 641-661. <https://doi.org/10.1016/j.ijhcs.2008.04.004>
- Johnson, M. K., & Raye, C. L. (1981). Reality monitoring. *Psychological Review*, *88*(1), 67-85. <https://doi.org/10.1037/0033-295X.88.1.67>
- Kandel E.R., & Schwartz J.H., & Jessell T.M., & Siegelbaum S.A., & Hudspeth A.J., & Mack S(Eds.), (2014). Intermediate-level visual processing and visual primitives. *Principles of Neural Science, Fifth Edition*. McGraw Hill.
- Kanizsa, G. (1979). *Organisation in Vision: Essays on Gestalt Perception*. New York: Praeger.
- Krugman, H. E. The Impact of Television Advertising: Learning Without Involvement. *Public Opinion Quarterly*, *29*(3). <https://doi.org/10.1086/267335>
- Li, L. -J., Su, H., Lim, Y., & Fei-Fei, L. (2012). Objects as Attributes for Scene Classification. *Trends and Topics in Computer Vision*, 57-69. https://doi.org/10.1007/978-3-642-35749-7_5
- Loomis, J. M. (1992). Distal Attribution and Presence. *Presence: Teleoperators and Virtual Environments*, *1*(1), 113-119. <https://doi.org/10.1162/pres.1992.1.1.113>

- Loschky, L. C., Hansen, B. C., Sethi, A., & Pydimarri, T. N. (2010). The role of higher order image statistics in masking scene gist recognition, *72*(2), 427-444. <https://doi.org/10.3758/APP.72.2.427>
- Lu, J., Xu, M., & Wang, Z. (2016). Predicting the memorability of natural-scene images. *2016 Visual Communications and Image Processing (VCIP)*, 1-4. <https://doi.org/10.1109/VCIP.2016.7805542>
- Lu, J., Xu, M., Yang, R., & Wang, Z. (2020). Understanding and Predicting the Memorability of Outdoor Natural Scenes. *IEEE Transactions on Image Processing*, *29*, 4927-4941. <https://doi.org/10.1109/TIP.2020.2975957>
- Lyu, M., Choe, K. W., Kardan, O., Kotabe, H. P., Henderson, J. M., & Berman, M. G. (2020). Overt attentional correlates of memorability of scene images and their relationships to scene semantics. *Journal of Vision*, *20*(9). <https://doi.org/10.1167/jov.20.9.2>
- Mamus, E., & Boduroglu, A. (2017). The role of context on boundary extension. *Visual Cognition*, *26*(2), 115-130. <https://doi.org/10.1080/13506285.2017.1399947>
- Mathews, A., & Mackintosh, B. (2004). Take a Closer Look: Emotion Modifies the Boundary Extension Effect. *Emotion*, *4*(1), 36-45. <https://doi.org/10.1037/1528-3542.4.1.36>
- Marr, D. (2010). *Vision: A Computational Investigation into the Human Representation and Processing of Visual Information*. MIT Press. <https://doi.org/10.7551/mitpress/9780262514620.001.0001>
- Marto, A., & Gonçalves, A. (2022). Augmented Reality Games and Presence: A Systematic Review. *Journal of Imaging*, *8*(4). <https://doi.org/10.3390/jimaging8040091>
- Masarwa, S., Kreichman, O., & Gilaie-Dotan, S. (2022). Larger images are better remembered during naturalistic encoding. *Proceedings of the National Academy of Sciences*, *119*(4). <https://doi.org/10.1073/pnas.2119614119>
- McMahan, A. (2003). 'Immersion, Engagement and Presence, A Method for Analysing 3-D Video Games' In: Wolf, M.J.P & Perron, B. (eds.) *The Video Game Theory Reader*. New York, USA: Routledge, Taylor & Francis Group, pp 77-78.
- McQuarrie, E.F., & Munson, J.M. (1992). A Revised Product Involvement Inventory: Improved Usability and Validity. *ACR North American Advances*.

- Ménétrier, E., & Didierjean, A. (2013). L'expertise en conduite automobile peut-elle moduler le phénomène d'extension des limites ?. *L'Année psychologique*, *113*(04), 523-545. <https://doi.org/10.4074/S0003503313014024>
- Ménétrier, E., Iralde, L., & Le Bohec, L. (2019). Spatial layout extrapolation in aging: underlying cognitive and executive mechanisms. *Visual Cognition*, *27*(9-10), 668-686. <https://doi.org/10.1080/13506285.2019.1634663>
- Microsoft Corporation (2022). *Microsoft Excel*. Retrieved from <https://office.microsoft.com/excel>
- Minsky, M. (1980). Telepresence. *Omni*, 45-51.
- Mullally, S. L., Intraub, H., & Maguire, E. A. (2012). Attenuated Boundary Extension Produces a Paradoxical Memory Advantage in Amnesic Patients. *Current Biology*, *22*(4), 261-268. <https://doi.org/10.1016/j.cub.2012.01.001>
- Munger, M. P., & Multhaup, K. S. (2016). No imagination effect on boundary extension, *44*(1), 73-88. <https://doi.org/10.3758/s13421-015-0541-3>
- Murray, J. H. (2016). *Hamlet on the Holodeck: The Future of Narrative in Cyberspace* (2nd ed.). The Free Press.
- Nanay, B. (2021). Boundary extension as mental imagery. *Analysis*, *81*(4), 647-656. <https://doi.org/10.1093/analys/anab023>
- Nilsson, N. C., Nordahl, R., & Serafin, S. (2016). Immersion Revisited: A review of existing definitions of immersion and their relation to different theories of presence. *Human Technology*, *12*(2), 108-134. <https://doi.org/10.17011/ht/urn.201611174652>
- Oliva, A., & Torralba, A. (2001). Modeling Shape of the Scene: A Holistic Representation of the Spatial Envelope. *International Journal of Computer Vision*, *42*(3), 145-175. <https://doi.org/10.1023/A:1011139631724>
- Oliva, A. (Ed.). (2005). Gist of the Scene. In L. Itti, G. Rees, & J. K. Tsotsos, *Neurobiology of Attention* (1st ed., pp. 251-256). Academic Press.
- Owens, J. W., Chaparro, B. S., & Palmer, E. M. (2019). Exploring website gist through rapid serial visual presentation. *Cognitive Research: Principles and Implications*, *4*(1). <https://doi.org/10.1186/s41235-019-0192-1>

- Parikh, D., Isola, P., Torralba, A., & Oliva, A. (2012). Understanding the intrinsic memorability of images. *Journal of Vision*, *12*(9), 1082-1082. <https://doi.org/10.1167/12.9.1082>
- Peirce, J. W. (2015). Understanding mid-level representations in visual processing. *Journal of vision*, *15*(7), 5. <https://doi.org/10.1167/15.7.5>
- Petty, R. E., Cacioppo, J. T., & Haugtvedt, C. P. (1992). Involvement and persuasion: An appreciative look at the Sherifs' contribution to the study of self-relevance and attitude change. In D. Granberg & G. Sarup (Eds.), *Social judgment and intergroup relations: Essays in honor of Muzifer Sherif* (pp. 147-175). New York: Springer-Verlag.
- Potter, M. C., Wyble, B., Haggmann, C. E. & McCourt, E. S. (2014). Detecting meaning in RSVP at 13 ms per picture. *Attention, Perception, & Psychophysics*, *76* (2), 270–279. doi: 10.3758/s13414-013-0605-z
- Psotka, J. (1995). Immersive training systems: Virtual reality and education and training. *Instructional Science*, *23*(5-6), 405-431. <https://doi.org/10.1007/BF00896880>
- Quinn, P. C., & Intraub, H. (2007). Perceiving "Outside the Box" Occurs Early in Development: Evidence for Boundary Extension in Three- to Seven-Month-Old Infants. *Child Development*, *78*(1), 324-334. <https://doi.org/10.1111/j.1467-8624.2007.01000.x>
- Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda, *147*. <https://doi.org/10.1016/j.compedu.2019.103778>
- Rasche, C., & Koch, C. (2002). Recognizing the gist of a visual scene: possible perceptual and neural mechanisms. *Neurocomputing*, *44-46*, 979-984. [https://doi.org/10.1016/S0925-2312\(02\)00500-3](https://doi.org/10.1016/S0925-2312(02)00500-3)
- Ravaja, N., Saari, T., Turpeinen, M., Laarni, J., Salminen, M., & Kivikangas, M. (2006). Spatial Presence and Emotions during Video Game Playing: Does It Matter with Whom You Play?. *Presence: Teleoperators and Virtual Environments*, *15*(4), 381-392. <https://doi.org/10.1162/pres.15.4.381>
- Rensink, R. A. (2000). Scene Perception. In A. E. Kazdin, *Encyclopedia of Psychology* (7 ed., pp. 151-155). Oxford University Press.

- Reeves, B., & Nass, C. (1996). The media equation - how people treat computers, television, and new media like real people and places.
- Reeves, B., Lang, A., Kim, E. Y., & Tatar, D. (1999). The Effects of Screen Size and Message Content on Attention and Arousal. *Media Psychology*, 1(1), 49-67. https://doi.org/10.1207/s1532785xmep0101_4
- Rigby, J. M., Brumby, D. P., Cox, A. L., & Gould, S. J. J. (2016). Watching movies on netflix. *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct*, 714-721. <https://doi.org/10.1145/2957265.2961843>
- Rothschild, M.L. (1984). Perspectives on Involvement: Current Problems and Future Directions. *ACR North American Advances*.
- Ross, M. G., & Oliva, A. (2010). Estimating perception of scene layout properties from global image features. *Journal of Vision*, 10(1), 2-2. <https://doi.org/10.1167/10.1.2>
- Rousselet, G. A., Fabre-Thorpe, M., & Thorpe, S. J. (2002). Parallel processing in high-level categorization of natural images. *Nature Neuroscience*, 5(7), 629-630. <https://doi.org/10.1038/nn866>
- Safer, M. A., Christianson, S. -Å., Autry, M. W., & Österlund, K. (1999). Tunnel memory for traumatic events. *Applied Cognitive Psychology*, 12(2), 99-117. [https://doi.org/10.1002/\(SICI\)1099-0720\(199804\)12:2<99::AID-ACP509>3.0.CO;2-7](https://doi.org/10.1002/(SICI)1099-0720(199804)12:2<99::AID-ACP509>3.0.CO;2-7)
- Sanocki, T. (2003). Representation and perception of scenic layout. *Cognitive Psychology*, 47(1), 43-86. [https://doi.org/10.1016/S0010-0285\(03\)00002-1](https://doi.org/10.1016/S0010-0285(03)00002-1)
- Seamon, J. G., Schlegel, S. E., Hiester, P. M., Landau, S. M., & Blumenthal, B. F. (2002). Misremembering Pictured Objects: People of All Ages Demonstrate the Boundary Extension Illusion. *The American Journal of Psychology*, 115(2). <https://doi.org/10.2307/1423432>
- Sheridan, T. B. (1992). Musings on Telepresence and Virtual Presence. *Presence: Teleoperators and Virtual Environments*, 1(1), 120-126. <https://doi.org/10.1162/pres.1992.1.1.120>
- Slater, M. (2003). A Note on Presence Terminology, 3(3), 1-5.
- Slater, M., & Wilbur, S. (1997). A Framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual Environments. *Presence:*

Teleoperators and Virtual Environments, 6(6), 603-616.
<https://doi.org/10.1162/pres.1997.6.6.603>

Stevens, J. A., & Kincaid, J. P. (2015). The Relationship between Presence and Performance in Virtual Simulation Training. *Open Journal of Modelling and Simulation*, 03(02), 41-48. <https://doi.org/10.4236/ojmsi.2015.32005>

Takarangi, M. K. T., Oulton, J. M., Green, D. M., & Strange, D. (2016). Boundary Restriction for Negative Emotional Images Is an Example of Memory Amplification. *Clinical Psychological Science*, 4(1), 82-95. <https://doi.org/10.1177/2167702615569912>

Takatalo, J., Häkkinen, J., Kaistinen, J., & Nyman, G. (2010). Presence, Involvement, and Flow in Digital Games. *Evaluating User Experience in Games*, 23-46. https://doi.org/10.1007/978-1-84882-963-3_3

The jamovi project (2021). *jamovi*. (Version 2.2) [Computer Software]. Retrieved from <https://www.jamovi.org>.

Thompson, M., Nordin, I. A., & Cairns, P. (2012). Effect of touch-screen size on game immersion. *BCS-HCI '12: Proceedings of the 26th Annual BCS Interaction Specialist Group Conference on People and Computers*, 280-285. <https://doi.org/10.5555/2377916.2377952>

Thornton, I. M., & Hubbard, T. L. (2010). Representational momentum: New findings, new directions. *Visual Cognition*, 9(1-2), 1-7. <https://doi.org/10.1080/13506280143000430>

Troscianko, T., Meese, T. S., & Hinde, S. (2012). Perception While Watching Movies: Effects of Physical Screen Size and Scene Type. *I-Perception*, 3(7), 414-425. <https://doi.org/10.1068/i0475aap>

Wilder, J., Dickinson, S., Jepson, A., & Walther, D. B. (2018). Spatial relationships between contours impact rapid scene classification. *Journal of Vision*, 18(8). <https://doi.org/10.1167/18.8.1>

Witmer, B. G., & Singer, M. J. (1998). Measuring Presence in Virtual Environments: A Presence Questionnaire. *Presence: Teleoperators and Virtual Environments*, 7(3), 225-240. <https://doi.org/10.1162/105474698565686>

Witmer, B. G., Jerome, C. J., & Singer, M. J. (2005). The Factor Structure of the Presence Questionnaire. *Presence: Teleoperators and Virtual Environments*, 14(3), 298-312. <https://doi.org/10.1162/105474605323384654>

Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology*, 81(1), 141-145. <https://doi.org/10.1037/h0027474>

Zhang, C., Perkiš, A., & Arndt, S. (2017). Spatial immersion versus emotional immersion, which is more immersive?. *2017 Ninth International Conference on Quality of Multimedia Experience (QoMEX)*, 1-6. <https://doi.org/10.1109/QoMEX.2017.7965655>

List of used abbreviations

Abbreviation	Meaning
BE	Boundary extension
CC	Close-up followed by a close-up (in presentation of stimuli)
CW	Close-up followed by a wide-angle
Ppi	Pixels per inch
px	Pixels
RSVP	Rapid serial visual presentation
vmPFC	ventromedial prefrontal cortex
WC	Wide-angle followed by a close-up
WW	Wide angle followed by a wide angle

Appendix A – Informed Consent

Informace k účasti na experimentech v laboratoři Labels a vyjádření informovaného souhlasu

Byli jste vyzváni, abyste se v rámci plnění požadavků k atestaci v jednom z vašich kurzů zúčastnili experimentu v laboratoři Labels, společného pracoviště Psychologického ústav AV ČR a FF UK. Informace obsažené na této stránce slouží jako podrobnější informace.

Cíl a obsah výzkumu

Experimenty, jichž se máte zúčastnit, se mohou týkat různých aspektů zpracování informací nebo jazykových podnětů lidmi. Cílem je studovat, jakým způsobem lidé zpracovávají podněty různého typu, jak je vnímají, rozumějí jim, případně jak je ukládají do paměti, co se děje při soustředěné pozornosti na podnět a podobně. Při experimentu budete obvykle žádáni, abyste sledovali na obrazovce počítače různé podněty, např. slova nebo geometrické tvary, a reagovali na ně podle zadání. V některých experimentech budou při prezentaci měřeny některé fyziologické projevy, jako např. oční pohyby. Mohou vám být prezentovány i úlohy, k jejichž předkládání nebude využíván počítač, ale které vám zadá asistent. Zde se může jednat o odpovídání na různé otázky, plnění úloh a reagování na předložené podněty.

Přínosy

Základním přínosem vaší účasti v experimentu je, že přispějete k řešení různých vědeckých otázek týkajících se lidské mysli a jejího fungování. Pro vás osobně představuje pouze minimální přínos, a to v tom, že vám umožní si osobně vyzkoušet pozici testované osoby a poznat tak některé procedury, o nichž můžete číst v učebnicích a v odborné literatuře.

Rizika

Procedury v laboratoři nepřinášejí žádná rizika vyšší než běžný pobyt v kancelářském prostředí a práce s osobním počítačem či podobným elektrickým spotřebičem.

Během experimentů budeme z evidenčních důvodů sbírat některé vaše osobní údaje (jméno, obor studia) a údaje o vašem výkonu. Vaše osobní údaje nebudou sdělovány nikomu mimo výzkumný tým. Údaje o vašem výkonu v experimentech budou využity pouze pro vyhodnocení experimentů a nebudou samostatně sdělovány dalším osobám. Výsledky budou prezentovány nebo publikovány způsobem, který neumožňuje identifikaci výsledků jednotlivých osob.

Vaše práva

Účast v experimentu můžete kdykoli před koncem experimentu odmítnout nebo ukončit. Není vaší povinností se experimentu účastnit. Pokud je účast v experimentu požadavkem k atestaci z nějakého předmětu a vy se z nějakých důvodů nechcete účastnit, dohodněte si s vyučujícím daného předmětu náhradní formu splnění požadavku. Údaje získané během vaší účasti nemohou mít vliv na vaše hodnocení ve škole ani na žádné jiné vaše aktivity.

Potvrzuji, že jsem četl/četla uvedenou informaci a souhlasím s účastí na výzkumu.

Datum

Jméno a podpis

Appendix B – Form

Demografický dotazník

Jaké je Vaše pohlaví?

.....

Jaký je Váš věk?

.....

Máte vadu zraku (dalekozrakost/krátkozrakost/barvoslepost/jiné)?

.....

Pokud máte korekci zraku, máte nyní brýle/kontaktní čočky?

.....

Appendix C – Instructions

Vnímání fotografií na různě velkých obrazovkách

Děkuji, že jste se rozhodli zúčastnit výzkumu zkoumající efekt rozšiřování hranic u fotografií. Během následujících třiceti minut se budete účastnit dvou instancí experimentu – na mobilním zařízení a počítači.

V obou částech vám po zácvičku budou prezentovány skupiny tří fotografií scén, následované krátkou pauzou a vizuální maskou (výplňovým obrázkem). Tyto fotografie si pokuste zapamatovat, experiment tedy vyžaduje vaši plnou pozornost. Jakmile maska zmizí, bude vám prezentována jedna náhodně vybraná fotografie ze tří dříve zobrazených a budete vyzváni k porovnání zachycené scény. Vaším úkolem bude určit zdali nově zobrazená fotografie zachycuje scénu z větší vzdálenosti, menší vzdálenosti či zůstala stejná. Dále budete vyzváni k vyjádření míry jistoty vašeho určení. Tento proces budete opakovat po zácvičku celkem osmkrát na každém zařízení.



Každý obrázek prezentován po dobu 3 sekund.



Vizuální maska, prázdná obrazovka a jedna ze tří dříve prezentovaných fotografií s posuzovací škálou:

V porovnání s dříve prezentovanou fotografií mi scéna na této fotografii připadá:

“Dále/Lehce dále/Stejná/Lehce blíže/ Blíže”

Poté zobrazena škála pro posouzení jistoty odpovědi:

Jak moc jsem si svou odpověď jistý/á:

“Nejistý/á”, “Docela jistý/á”, “Jistý/á”

Výsledky experimentu budou anonymizovány a využity v rámci diplomové práce.