Contextual Effects in Consumer Research

An Investigation of Consumer Information Processing and Behavior via the Application of Eye-tracking Methodology

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WWW.CBS.DK

ISSN 0906-6934

Print ISBN: **978-87-93744-96-7**
Online ISBN: **978-87-93744-97-4**

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PhD Series 27-2019

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PhD School in Economics and Management | **PhD Series 27.2019**

CBS COPENHAGEN BUSINESS SCHOOL
HANDELSHØJSKOLEN

PhD Dissertation
Copenhagen Business School
Department of Marketing

Seidi Suurmets
May 2019

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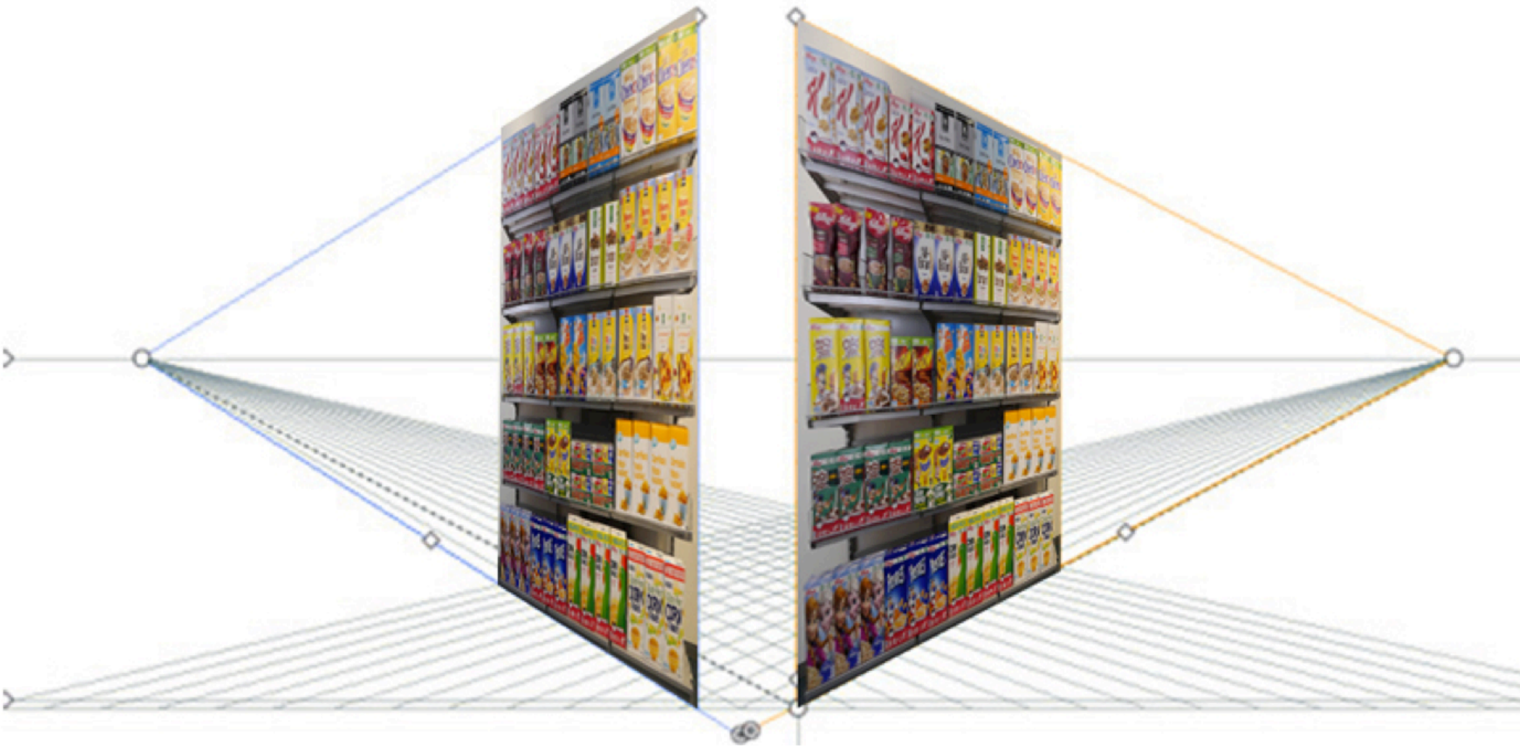

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1st edition 2019
PhD Series 27.2019

ISSN 0906-6934
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The PhD School in Economics and Management is an active national and international research environment at CBS for research degree students who deal with economics and management at business, industry and country level in a theoretical and empirical manner.

Preface

The present work is an article-based dissertation, submitted in fulfillment of the requirements for a PhD degree from Copenhagen Business School (CBS).

The project was funded by Innovationsfonden and was carried out in cooperation between Copenhagen Business School and iMotions AS. The student, Seidi Suurmets was employed full-time as a PhD Fellow in the Department of Marketing at Copenhagen Business School, but ran additional projects in collaboration with iMotions AS.

The core of the dissertation consists of three separate articles, each of them employs eye-tracking methodology and focuses on the aspect of validity in consumer research.

In the introduction the need for investigating the external validity of lab-based findings is established. Also an outline of the content and the key contributions of each of the three articles is provided in introductory terms. This is followed by a chapter on theoretical background, which introduces the fields of marketing and consumer research and outlines the positioning of this dissertation in relation to consumer research literature. Also a brief overview of the application of eye-tracking methodology in consumer research is provided. The remainder of the dissertation is organized into the following chapters: methodology; the three articles; conclusion and general discussion; contributions to theory and business; and implications for further research.

Abstract

As traditional approaches to consumer research are based on theoretical and methodological approaches that limit the external validity of the findings, this dissertation employs eye-tracking methodology in order to investigate the impact of the study setup and contextual cues on consumer information processing and aims to contribute to the discourse and methodology related to conducting studies in real life environments. With the focus on investigating the external validity of laboratory-based findings, the empirical studies reveal that (1) there are spatial differences in attention allocation to stimuli presented as screen-images versus in their physical form, and (2) the relative impact of stimulus-driven versus goal-oriented factors in guiding attention during choice process is affected by the study setup. These findings have important implications for both researchers and practitioners. Addressing the issue of visualizing eye-tracking data from mobile environments, also a novel approach for constructing three-dimensional heatmaps is introduced. Finally, recommendations for future research are proposed.

The tree articles included in this dissertation are:

- Suurmets, S., Clement, J., Nyberg, A., Nikolaou, E. Computer screen or real life: Comparing the allocation of visual attention in remote and mobile settings
- Suurmets, S. Consumers in and out of context: Investigation of Visual attention during choice process in different study setups
- Suurmets, S., Clement, J., Stets J. D., Jensen, R. R. 3D heatmap in marketing research and marketing practice – validation of an integrating model

Abstrakt

Traditionelle tilgange til at undersøge forbrugeradfærd indenfor marketing, er mestendels baseret på teori og metoder med begrænset ekstern troværdighed. Det gælder i særlig grad ved undersøgelser af den adfærd der påvirkes af korte visuelle påvirkninger. Denne afhandling benytter eye-tracking med henblik på at undersøge og kortlægge hvordan undersøgelsesopsætningen (set-up) og indholdsbaseret referencer (kontekstuelle tegn) påvirker forbrugernes informationsbehandling. Hermed bidrager afhandlingen til diskursen om metodisk validitet forbundet med at designe og udføre undersøgelser i virkelige omgivelser. Med særlig fokus på at undersøge ekstern validitet af laboratoriebaseret resultater, viser de empiriske forsøg at (1) der er en rummelig (spatial) forskel på forbrugernes visuelle opmærksomhed afhængigt af om stimuli bliver præsenteret på en computerskærm (to-dimensional) eller fysisk præsenteret (tre-dimentional). De empiriske forsøg viser ligeledes, at (2) undersøgelsesopsætningen påvirker forbrugeropmærksomheden i relation til stimuli drevet faktorer (designet af den iagttagede genstand) overfor de målorienterede faktorer (de semantiske elementer der ledes efter). Disse resultater har en afgørende betydning og konsekvens for akademikere/forskere ved design af eksperimenter og for praktikere ved evaluering af resultater med data fra eye-tracking. Ydermere introducere afhandlingen en ny fremgangmåde for fremstilling af tredimensionelle heatmaps som gør det muligt at italesætte visualisering af opmærksomhed af skabt fra eye-tracking data i virkelige omgivelser. Afslutningsvist, afdækkes forslag til fremdige undersøgelser.

De tre artikler, der er inkluderet i afhandlinger er:

- Suurmets, S., Clement, J., Nyberg, A., Nikolaou, E. Computer screen or real life: Comparing the allocation of visual attention in remote and mobile settings
- Suurmets, S. Consumers in and out of context: Investigation of Visual attention during choice process in different study setups
- Suurmets, S., Clement, J., Stets J. D., Jensen, R. R. 3D heatmap in marketing research and marketing practice – validation of an integrating model

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1. INTRODUCTION

1. Introduction

"*Consumers are not disembodied minds floating through space, but are instead biological machines whose behaviors are intimately tied to physical states*"

(Williams & Poehlman, 2016, p. 244)

The discipline of consumer research grew out from early marketing theories that were grounded in economic models and represented consumption decisions in a 'deliberative equilibrium' (Camerer, Loewenstein, & Prelec, 2005). Over time, consumer behavior research drew from various other disciplines, but the development of the field was most influenced by theories of cognitive and social psychology, and to a lesser degree, behavioral decision theory and postmodern approaches (Simonson, Carmon, Dhar, Drolet, & Nowlis, 2001; Tybout & Artz, 1994). Traditional explanations of consumer behavior that are rooted in cognitive psychology assume that when consumers evaluate, choose or buy, they engage in conscious and elaborate information processing. Information processing then has an impact on attitudes, which in turn may or may not affect choices (Dijksterhuis, Smith, & Baaren, 2005). In other words, the predominant view in traditional consumer research is that attitudes are cognitively activated and lead to downstream effects on decision making process. However, it can be argued that an approach based solely on conscious information processing can only account for a limited subset of choices that consumers make. A substantial proportion of human motivations lie below the level of consciousness and accordingly, consumer evaluations and choices can occur intuitively, automatically and without any conscious control or effort (Bargh, 2002; Dijksterhuis, Smith, Van Baaren, & Wigboldus, 2005; Ohme, Matukin, & Pacula-Lesniak, 2011).

Consumer decision making should therefore not be regarded merely as a conscious process of weighing of costs and benefits. On the contrary, purchase decisions can be habitualized or driven by attitudes that are automatically activated on the perception of a product. Such attitudes are malleable and context-dependent, reflecting both the social environment and current goals

(Ferguson & Bargh, 2004). Furthermore, consumers are generally unaware of the moderating effects of subtle influences, such as mere perceptual fluency or the misattribution of familiarity (Fitzsimons et al., 2002). Research on priming and situational activation of mental constructs have demonstrated that even subtly presented environmental cues can have powerful effects on behavior. Environmental cues can also activate goal pursuit where goal-directed behavior takes place entirely outside conscious awareness (Chartrand & Bargh, 1996; Chartrand, Huber, Shiv, & Tanner, 2008). This, in turn, can lead to impulse purchases, where decisions bypass the influence of rational deliberation (Dijksterhuis, Smith, Van Baaren, et al., 2005). Thus, consumer decision process can be described as a complex interplay between conscious and nonconscious processes, where the impact of explicit memory, attitudes, and preferences is intertwined with processes that may operate outside awareness, such as affective processes and goal pursuit (Bargh, 2002; Fitzsimons et al., 2002).

Early social-cognitive models underlying a large part of consumer research not only assumed conscious information processing, but as described by Bargh (2002), relied on studies conducted in controlled, quiet and distraction-free laboratory settings. In these experiments the participants followed the instructions given explicitly by the experimenter, gave their full attention to the stimuli presented, and had plenty of time to consider the response. However, when these studies were moved to more naturalistic, i.e. noisy and busy real-life settings, the main feature that dropped out of these models was the role played by deliberate conscious choice process (Bargh, 2002; Bargh & Chartrand, 1999). This indicates that compared to artificial lab settings, the behavior and evaluations in naturalistic environments are to a large degree driven by automatic processes and affective responses, and thus, can be modulated by an enormous number of sensory variables, hedonic states, expectations, priming and social context (Dijksterhuis, Smith, Van Baaren, et al., 2005; McClure et al., 2004). With regards to environmental variables, the mere presence or occurrence of an object or event can impact responses in an immediate and automatic manner, and correspondingly, atmospheric cues have been shown to have a robust influence on consumers' emotions, evaluations and behavior

(Sherman, Mathur, & Smith, 1997; Turley & Milliman, 2000; Xiao & Nicholson, 2013). Even though the issue of generalizability of lab-based experiments is generally acknowledged, there is ambiguity related to how and to which degree the study setting impacts consumer responses and behavior.

A large part of traditional consumer research is built upon self-reported measures, relying on methods such as surveys, interviews and focus groups. However, approaches based on a purely conscious and intrapersonal perspective fail to account for nonconscious influences that the environment may exert (Dijksterhuis, Smith, & Baaren, 2005). Namely, when responses are driven by stimuli or processes that occur below the level of conscious awareness, the insights that consumers have regarding their preferences, attitudes or motives behind their behavior tend to be inadequate (Fitzsimons et al., 2002). To exemplify, a visual stimulus reaches consciousness approximately 300ms after it appears (Libet & Kosslyn, 2004), and conscious reports require not only visual awareness but also attention (Lamme, 2003). Events registered by the brain below this threshold or not paid attention to, hence, cannot be reported verbally, but can still have an impact on an individual's responses and behavior (Kenning, Plassmann, & Ahlert, 2007). Thus, self-reported conscious measures have significant limitations in providing an effective measure of internal reactions to external stimuli (Ohme et al., 2011). This underlines the relevance of employing biometric techniques such as eye-tracking in consumer research. Psycho-physiological approaches can significantly contribute to our understanding of cognition, emotions and behavior as they allow to investigate processes and responses that often are not accessible for conscious awareness (Cacioppo, Tassinary, & Berntson, 2007).

To conclude, there are three important factors that limit the credibility of the findings derived from traditional approaches to consumer behavior: the exclusion of nonconscious influences, the laboratory-based study environment, and the reliance on self-declarative methods. With regards to methodological considerations, biometric techniques have the advantage of providing insights in mental processes that may not be consciously accessible. However, the degree to which consumer responses and behavior are influenced by the characteristics of the study setting needs further investigation. Even though the aspect of external validity in consumer research has received considerable attention (Lynch Jr, 1982; Winer, 1999), only a limited number of studies have addressed the differential psychological or psychophysiological effects of the study setting on consumer responses and behavior.

Humans acquire a great majority of sensory information through vision, and visual attention can be regarded as the key coordinating mechanism in charge of maintaining information processing and other goals over time (LaBerge, 1995; Wedel & Pieters, 2008a). Visual attention is also central to the processing of visual marketing stimuli, and eye movements, that can be measured objectively and unobtrusively via the application of eye-tracking methodology, can offer valuable insights in processes underlying consumer behavior. In line with these arguments, this dissertation sets out to investigate consumer information processing and behavior in different study settings by focusing on the allocation of visual attention, and aims to contribute to the discourse and methodology related to conducting studies in real life environments.

1.1 Outline

The main body of this dissertation consists of three articles, which are all to be published in academic journals. The central issue that all three articles address is related to the aspect of validity: Articles 1 and 2 investigate the external validity of findings derived from artificial settings, and Article 3 focuses on improving the validity of the method of constructing heatmaps based on eye-tracking data from three-dimensional study environments.

From the perspective of consumer research, Article 1 focuses on information processing and aims to answer two questions:

- Are there differences in terms of how consumers allocate attention to stimuli presented in their physical form versus as screen images?
- How does the allocation of attention differ in these two conditions?

Having explored the impact of the stimulus display method on consumer information processing, Article 2 moves on to investigate the impact of the study setup on consumer choice behavior. Comparing consumer choice process in three different settings, in front of a screen, a mock shelf and in a real-life supermarket, the article addresses the following questions:

- Are there differences in consumer decision-making process in different study setups?
- To which degree do the findings established in the literature generalize to different approaches of studying consumer choice process?

Article 3 has a more methodological approach and focuses on the visualization of eye-tracking data. It addresses the question:

- How to create valid heatmap visualizations of eye-tracking data when the studies are conducted in three-dimensional environments?

An overview of the articles with regards to the methodology, thematic focus and contributions are presented in Table 1. The following section introduces the articles and provides a brief description of their content, findings, and contributions.

Table 1: Overview of the articles included in the dissertation

	Article 1		Article 2	Article 3
	Study 1	Study 2		
Sample (Initial) Included	(51) 20	(63) 56	(87) 63	12
Design	Within-subject	Between-subject	Between-subject	Single sample
Methodology	Eye-tracking	Eye-tracking	Eye-tracking	Eye-tracking
Manipulation	Screen image vs. Physical form	Screen image vs. Physical form	Screen image, Mock shelves & Supermarket environment	Comparison of two methodological approaches
Task	Free-viewing	Free-viewing	Forced choice	Forced choice
Stimuli	Banners, physical shelves	FMCG (tea, cereal) packages	FMCG (cereal) product display	FMCG (cereal) product display
Main theoretical contributions	Differences in spatial distribution of attention	Differences in attention allocated to stimulus areas with different semantic content and the pace of screening the scene	1) Differences in decision time and the proportion of alternatives attended 2) Differences in how stimulus-related vs. goal-driven factors guide attention	Impact of viewers' distance and viewing angle on the validity of gaze mapping and construction of heatmaps.
Methodological contributions	External validity of eye-tracking studies: the impact of the stimulus presentation method		External validity of eye-tracking studies: the impact of the study setting	Construction of 3D heatmaps

Article 1

Title:	Computer screen or real life: Comparing the allocation of visual attention in remote and mobile settings
Authors:	Seidi Suurmets, Jesper Clement, Amanda Nyberg, Elli Nikolaou
To be submitted to:	Journal of Consumer Research

Article 1 focuses on the spatial differences in gaze allocation to stimuli presented on the screen versus in their physical form and comprises of two separate studies. The first study reveals that when exposed to a shelf display and advertising banners in the physical display condition, less attention is allocated to the lower visual field, and fixations tend to be less spread out, as compared the screen-based setting. However, as the stimuli in the two conditions vary significantly with regards to their dimensions, the differences are likely caused by different (oculo-)motor processes.

In the second study the stimulus dimensions are kept constant. The findings reveal differences in total fixation duration to package design elements with different semantic content in the two conditions. Namely, when viewing packages in their physical form, viewers tend to gaze more at the pictorial element of the package, whereas in screen-viewing condition more attention is allocated to textual elements. The screen-based stimulus display can also facilitate a more rapid screening of the scene, as indicated by shorter values of time to first fixation (TTFF) metric.

The findings indicate that consumer visual attention, and thus also the processes of information acquisition and encoding, are influenced by the stimulus display method. This has ramifications on the generalizability of the findings from screen-based setups to real-life settings, and hence has important implications for both researchers and practitioners. To obtain more valid measures of how consumers attend physical objects in a three-dimensional world, stimuli should be presented in their physical form rather than as screen images.

Article 2

Title:	Consumers in and out of context: Investigation of visual attention during choice process in different study setups
Author:	Seidi Suurmets
Submitted to:	Journal of Business Research, Special Issue on Eye Tracking Applications in Marketing

Article 2 focuses on differences in consumer choice process and the allocation of visual attention in three different setups: in front of a computer screen, in the lab with a mock shelf and in a real-life supermarket. The aim of the study is to investigate the degree to which the findings established in the literature can be generalized across different experimental setups.

In all experimental conditions the participants are exposed to a product display of morning cereal and instructed to select the preferred item. The analysis focuses on the differences in decision time and the proportion of alternatives attended, as well as the proportional viewing time allocated to the center of the display, to different shelf levels and to alternatives with different number of facings.

The findings reveal that not only the general characteristics of the choice behavior, but also the relative impact of stimulus-driven versus goal-oriented factors in guiding attention are affected by the study setup and the confounding factors it entails. In the mock shelf condition participants attended more choice alternatives and spent significantly longer time to reach the decision than in the other two conditions. Unlike in store and screen-viewing conditions where a higher number of facings led to a longer proportional viewing time, participants in the mock-shelf condition spent relatively longer time attending the choice alternatives with a lower number of facings. Also the attention allocated to different shelf levels differed across the three conditions. Furthermore, in the screen-viewing condition the center of the display played a more important role in guiding attention than in the store condition.

These findings suggest that the factors guiding visual attention during consumer choice process are closely tied to the characteristics of the experimental setup. The study therefore contributes to the discourse on experimental realism in consumer research and warrants researchers and practitioners against overgeneralizing findings from one experimental context to another.

Article 3

Title:	3D heatmap in marketing research and marketing practice – validation of an integrating model
Authors:	Seidi Suurmets, Jesper Clement, Jonathan D. Stets, Rasmus R. Jensen
Submitted to:	International Journal of Research in Marketing

Having established that consumer information processing and choice process are strongly influenced by the characteristics of the study setup, Article 3 addresses the aspect of visualizing eye-tracking data from mobile environments. Unlike two-dimensional screen-images, stimuli in real-life environments can be gazed from different distances and viewing angles, and the mapping of gaze data should take these variables into consideration. The methodology of heatmaps was developed based on the viewing of two-dimensional stimuli, but as more and more studies are conducted in three-dimensional environments, the construction of 3D heatmaps has methodological relevance also outside marketing.

As previously stated, Article 3 has a more methodological approach and its main contribution is proposing the method for constructing 3D heatmaps. The article presents an example demonstrating the differences in heatmaps using two different approaches and outlines the errors that result from traditional 2D gaze mapping. Furthermore, the traditional method of constructing heatmaps from mobile environments involves manual mapping of gaze points from video frames to a reference image. The novel method presented in the article allows to automize this process, potentially saving researchers and practitioners a great number of man-hours. Thus, the article makes a contribution for helping to move eye-tracking studies from laboratory to real-life environments.

2. THEORETICAL FRAMEWORK

2. Theoretical framework

2.1 The discipline of marketing

Marketing historians trace the history of marketing discipline back to the beginning of the twentieth century and recognize Edward David Jones for teaching the first university course in marketing. Already during the period from 1903 to 1913, Jones wrote about the evolution of marketing methods, the efficiency of marketing process and the functional approach to marketing (Jones & Monieson, 1990). Until then, it was the economic theory that provided the necessary explanations for decision-making activity and guidelines for business and government actions (Morgan, 1996). Early writings in marketing, however, were mainly descriptive. It was first in the 1940s when marketing as a scientific discipline started to receive theoretical attention, with contributions from researchers such as Alderson and Cox (1948) and Bartels (1951).

The role of marketing within firms formally developed in the early 1950s, growing out of the post-war business environment, where the focus was on product and production, rather than on the consumers' needs (McGee & Spiro, 1988). Until then, the business world saw the main function of marketing as selling what the factory could produce, which implies a short-term focus with the emphasis on tactical sales techniques. In the 1950s, however, the economy had matured into a consumer society, where an abundance of manufacturers and brands had to compete for increasingly affluent consumers' share of wallet (Webster Jr, 1988). This led to the adoption of the so-called marketing management concept, where the consumer had to be recognized and accepted as the focal point for all business activities and decisions (Raymond & Barksdale, 1989)

The new customer-oriented business philosophy involved a long-term, strategic approach where customer satisfaction, market segmentation, and product differentiation were regarded as the key to profitability (Webster Jr, 1988). It also led to the integration of the elements in the marketing mix – products, prices, promotion and distribution (corresponding to the foundational 4Ps model that grew out from the work of Culliton (1948), Borden (1964) and McCarthy (1964)). One of the first statements arguing that marketing was a general management responsibility was made by Peter Ducker:

> ”*There is only one valid definition of business purpose: to create a satisfied customer. It is the customer who determines what the business is. Because it is its purpose to create a customer, any business enterprise has two - and only these two - basic functions: marketing and innovation.* ”
> (Drucker, 1954, p. 37)

This perspective was also supported by the academic community, as exemplified by a statement by an economist Theodore Levitt: “… *the organization must learn to think of itself not as producing goods and services but as buying customers, as doing things that will make people want to do business with them*”(Levitt, 1960, pp. 45–56).

There can be distinguished between several different schools of marketing thought. Roughly paralleling the four “4 Eras” proposed by Wilkie and Moore (2003), Shaw and Jones (2005) divide it in four time periods: (1) Pre-Academic Marketing Thought, prior to 1900; (2) Traditional Approaches to Marketing Thought, from about 1900 to 1955; (3) the Paradigm Shift, based on Alderson’s work, from about 1955 to 1975; and (4) the Paradigm Broadening, mostly following Kotler’s writings, from approximately 1975 to 2000 (Shaw & Jones, 2005).

The discussion of different approaches and models in marketing domain could cover thousands of pages, but that would be out of the scope for this dissertation. Having provided a brief introduction to the development of marketing as a discipline, the following section discusses the development and different paradigms in consumer research.

2.2 The discipline of consumer research

Originally drawing from economics where a consumer was regarded as 'utility maximizer', over time various streams of psychology, sociology and anthropology have significantly influenced the development of consumer behavior research in marketing thought. As a school of marketing thought, consumer behavior started to gain momentum in the 1960s. The first chapter on "Consumer Analysis" published in the *Annual Review of Psychology*, for example, provided a brief review of motivation research and subliminal advertising (i.e. popular topics in the 1950s), and focused on survey techniques and methodological aspects of consumer research (Guest, 1962). First consumer behavior textbooks and courses appeared in the late 1960s, and in 1969 also The Association for Consumer Research (ACR) was founded (Simonson et al., 2001). At this early stage of development, concepts and ideas from different fields were integrated into comprehensive models (Shaw & Jones, 2005), implicitly assuming that buyer behavior can be captured as a single 'grand theory' (Simonson et al., 2001).

At the beginning of 1980s, however, consumer research went through an interpretive turn (Sherry, 1991), which can be attributed to two critical trends in the field of marketing - the rise of relationship marketing in 1970s, and of experiential marketing some years later. While traditional marketing operates from a neopositivist perspective, relationship and experiential marketing are positioned more towards postmodernism, denying any form of rationalization and arguing for the heterogeneous nature of reality (Addis & Podesta, 2005). In the domain of consumer research, the first critical attacks towards the traditional view date back to 1982, when Hirchman and Holbrook published a comparison of the traditional and the experiential approach to the study of consumer behavior, criticizing the thesis of consumer rationality and utilitarianism assumed by traditional theorists (Holbrook & Hirschman, 1982).

Correspondingly, consumer research literature can be viewed as comprising of different schools of thought. According to Østegaard and Jantzen (2000), there can be distinguished between four different perspectives that have been coexisting since the beginning of the development of marketing theory, but had their heyday in different periods of time. These perspectives differ with regards to their scientific foundation, the ontology of consumption, and how the consuming individual is perceived. These perspectives are: (1) Buyer behavior, based on behaviorist psychology; (2) Consumer behavior, based on cognitive psychology; (3) Consumer research, based on existential psychology; and (4) Consumption studies, based on cultural and social theories (Østergaard & Jantzen, 2000). While the former two perspectives follow a positivist philosophy, the Consumer research perspective is seen as equivalent to the interpretive turn (Sherry, 1991). The fourth perspective, Consumption studies deviates from the other three perspectives because the analysis extends beyond the single consuming individual, and the authors suggest that it is time for marketing theory to leave the dominant individualistic paradigm, and move towards social and cultural theory in order to establish contact with recent developments in sociology and anthropology (Østergaard & Jantzen, 2000).

Parallel to the changes in epistemological and ontological orientations, also the emphasis placed on different topics within consumer psychology has changed over time. Based on a literature review, Simonson and colleagues (2001) found that there had been a relative increase in the proportion of cognitive topics such as behavioral decision making, memory and knowledge, language, variety seeking and preconscious processing. Also social topics such as cross-cultural and ethnic influences on buyer behavior, the development of children as consumers, and gender differences had become more central. In contrast, research focusing on attitudes, as well as on family and social influences, reference groups, attribution, and self-perception had declined in importance (Simonson et al., 2001).

Social cognition approaches and behavioral decision theory focusing on judgment and choice share many of the same research values and methods, which place them on the positivist end of the spectrum (ibid.). The modern or positivist view involves the operationalization of constructs, statistical testing of hypotheses, and measurement of phenomena that can be explained with psychological constructs (Tybout & Artz, 1994). Whereas positivist research focuses on causation and explanations around issues such as purchase decisions, the postmodern perspective believes in a more subjective view of data interpretation, and emphasises specific consumption experiences and various novel areas, for example, related to lifestyles or semiotic perspectives (Simonson, Carmon, Dhar, Drolet, & Nowlis, 2001). The postmodern approach has been argued to contribute to consumer research in various ways, including uncovering new constructs, revealing the multidimensional nature of variables studied, and introducing multi-methodological perspectives that allow for triangulation of results (Tybout & Artz, 1994). For example, the existing research has demonstrated the influence of limiting cultural assumptions, transfers of cultural meanings, as well as the symbolic meaning of possessions and their role in constructing self-identity (ibid.).

The dispute between positivist and interpretivist approaches is also evident when reviewing different accounts on marketing and consumer research. For example, Tybout and Artz (1994) describe consumer psychology as a discipline that involves most of the elements of human psychology but focuses mainly on social and cognitive domains. According to this account, consumer psychology examines how consumers process information, form judgments, and in turn, how decision-making is affected by memory and judgments. Elaboration and cognitive resources are considered as central constructs with the main idea that elaboration is a resource-demanding activity (Tybout & Artz, 1994). However, the foundational forms underlying the field of psychology are under attack by postmodern thinkers, who deny the scientific method as a means to a valid or reliable inquiry, and postmodernism can therefore be considered one of the main theoretical challenges to existing marketing theories (Burton, 2001). Critical theory supports a move away from foundationalist approaches in social sciences, and towards more interpretive approaches, which has implications for the art versus science debate (Brown, 1996) and provides a new paradigm for research in marketing (Buttle, 1994). It has also been proposed that if postmodernism was to establish itself, then marketing could not defend its approach nor retain its current features and content (Addis & Podesta, 2005).

However, Simonson and colleagues (2001) predict that in the future the intensity of the postmodern-positivist debate will diminish, as there is significant room for collaboration and combining the advantages of both approaches, provided a sufficient degree of openness and tolerance on both sides. A strong exemplification of such combination is a framework of consumer psychology of brands, developed by Schmitt (2012). For five brand-related processes the author distinguishes between three levels of engagement: object-centered, self-centered and social engagement. Borrowing from social cognitive approaches, many of the elements (e.g. brand associations and categorization) are clearly based on the positivist paradigm. The element of brand symbolism, in contrast, is associated with consumer culture theory, covering socio-cultural symbolism and ideology of brands, as well as the enactment of archetype myths as recommended by Jungian analysis (Schmitt, 2012). The introduction of this comprehensive and pragmatic framework in the field of consumer psychology demonstrates a research approach where the choice of methods and research paradigms are mixed and play a subordinate role. Even though the epistemological basis of the conceptual framework for this model is not specified, it provides an integrative framework enabling a more systematic future research.

2.3 Positioning within the consumer research literature

Both marketing and consumer behavior research draw from various other disciplines, and this multidisciplinary perspective is well known and accepted (MacInnis & Folkes, 2009). Reflecting its applied orientation, marketing borrows theories, concepts, and methods from various disciplines, ranging from psychology, sociology, and anthropology to neuroscience, economics and statistics (Baron, Zaltman, & Olson, 2017). Approaching consumer behavior as a multidisciplinary subfield of marketing, MacInnis and Folkes (2009) describe it as covering three subthemes: Consumer Culture theory, Behavioral Decision

Theory and Information Processing, where the latter includes topics such as emotions or moods, memory, attitudes and conscious versus subconscious processes. Consumer behavior is regarded as a field open to adjoining disciplines, which include linguistics, psychology, neuroscience, economics, anthropology, sociology, literary criticism and history (MacInnis & Folkes, 2009). With regards to this categorization, this dissertation is positioned within the domain of information processing, and draws on the adjoining disciplines of psychology and, to a lesser degree, neuroscience, as visualized in figure 2

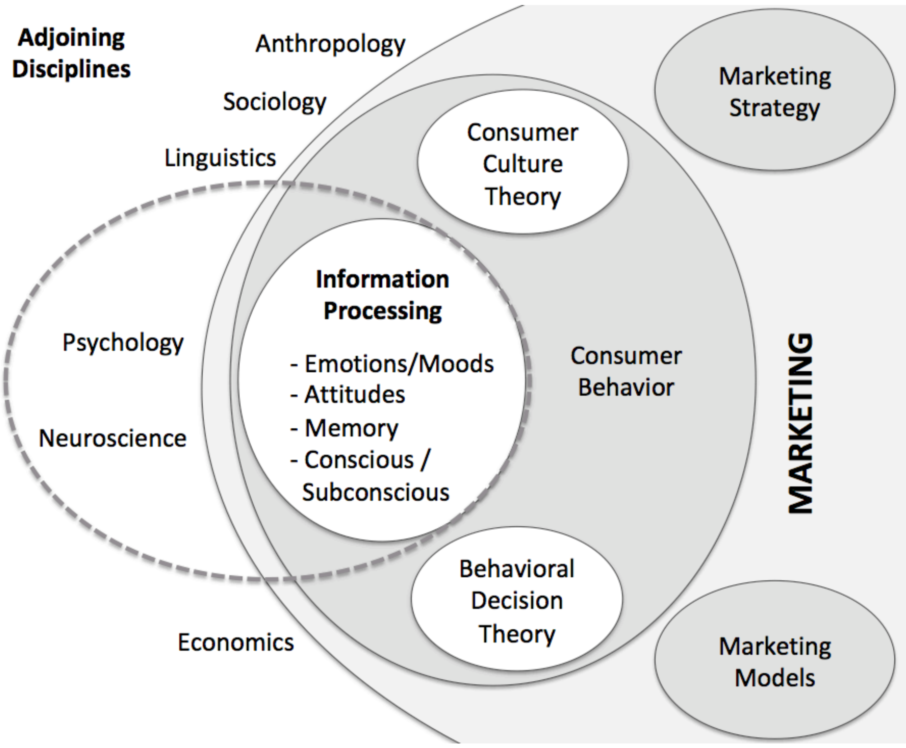

Figure 2: Consumer behavior as a multidisciplinary field of marketing, adapted from MacInnis & Folkes (2009, p. 910). The positioning of the dissertation is marked with the dashed line.

A different approach is adopted by Pham (2013) who views consumer behavior theory as a series of concentric circles. From the center towards the outside, these circles are signified as follows: Mechanical Core, Affective Layer, Motivational Ground, Social & Relational Context, and Cultural Background. With the focus on consumer information processing, as already established, this dissertation is closest related to the Mechanical Core element. Figure 3 presents an adapted version of Pham's (2013) concentric circles model of consumer behavior theory, and the right side column presents the topics that are relevant to the topic of this dissertation. Even though the aspects related to Affective Layer and Motivational Ground elements are not in the focus of this dissertation, it can be argued that affect and motivation also have an impact on attention, perception, sensory experiences and choice rules.

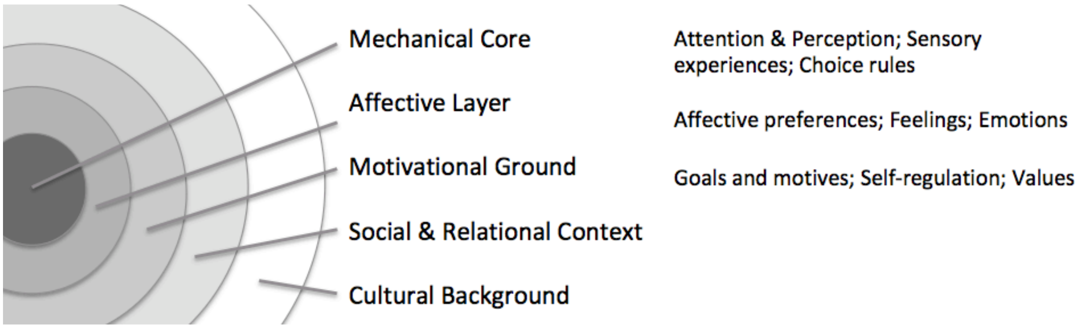

Figure 3: A concentric circles perspective of consumer behavior theory, adapted from Pham (2013, p. 416). Keywords in the right side columns represent the topics that the dissertation touches upon, however, the main focus is on the first innermost circle, the mechanical core.

Most research in the domain of consumer behavior during the past four decades has been dominated by three theoretical paradigms: cognitive psychology, social psychology and behavioral decision theory (Pham, 2013). Consumer psychology, when considered as a separate field of research, draws heavily on the theories and methods of cognitive and social psychology (Tybout & Artz, 1994) and accounts for a substantial proportion of consumer research (Zinkhan, Roth, & Saxton, 1992). However, because consumer psychology involves most of the elements of human psychology, it cannot be represented meaningfully in any single model or theory (Simonson et al., 2001). The domain of information processing within consumer psychology can be described as '*focusing on the interplay of affective and motivational processes on cognitive processes to understand areas like persuasion and implicit influences on consumer behavior*' (D. M. Bartels & Johnson, 2015, p. 48; Johar, Maheswaran, & Peracchio, 2006). This definition is also a good representation of the positioning of this dissertation

Reviewing the literature on consumer information processing, Johar and colleagues (2006) state that even though the dominant paradigm in consumer research involves conscious and deliberative processing, research has shown that people are influenced by automatic and nonconscious processes in their consumption-related behavior (Fitzsimons et al., 2002; Fitzsimons & Shiv, 2001; Janiszewski, 1993; Shapiro, 1999). Moreover, Bargh (2002), argues that nonconscious influences are likely to play an important role in consumer decision making and behavior, as there is a growing evidence that (1) much of social judgment and behavior occur without conscious awareness or intent, and (2) basic cognitive and reasoning process are substantially moderated by goal pursuits that often occur non-consciously. Referring to a fundamental asymmetry that all conscious processes are preceded and caused by nonconscious processing, whereas only some unconscious processes are prompted by conscious thought (Bargh & Morsella, 2008; Baumeister & Masicampo, 2010), Williams and Poehlman (2016) take it a step further and recommend researchers to 'consider consciousness second' when developing models of consumer behavior. Namely, the authors argue that researchers should begin their conceptual journeys by thoroughly considering how less obvious factors may or may not predict consumer behavior outcomes, and as a final step, determine the extent to which self-reportable causes provide additional insight into their phenomena of interest (Williams & Poehlman, 2016). Considering that self-reported verbal indicators may be biased due to cognitive distortions (Ohme et al., 2011) and cannot capture emotions and motivations occurring below the threshold of conscious awareness (Camerer et al., 2005; Fitzsimons et al., 2002), inquiries in consumer research should not be based on constructs that rely solely on self-reports.

Having established that non-conscious processes play an important role in consumer information processing, the interplay between perceptual, motivational and affective processes needs further elaboration. Consumer behavior, like other human endeavors, is ultimately goal-directed, and goals can be defined as desirable end-states that consumers, consciously or non-consciously, attempt to attain (Baumgartner & Pieters, 2008; Kopetz, Kruglanski, Arens, Etkin, & Johnson, 2012). Motivational processes, in this context, can be regarded as the driving force facilitating goal pursuit. In a chapter on goal-directed consumer behavior, Baumgartner and Pieters (2008) describe the process as follows:

- Affective states that are not related to goal pursuits can have direct and indirect effects on goal setting, as well as on the process of goal pursuit.
- When consumers pursue a specific goal, they focus on information that is relevant to goal achievement and tune out distracting information.
- Goal process is monitored by feedback loops, and affect arises when goal progress is thwarted or facilitated.
- Goal striving may be successful or unsuccessful, thus inducing positive or negative affective states.

The link between motivation and affect is therefore bidirectional- the process of goal pursuit both induces and is influenced by emotional responses. It is also evident that goal pursuit affects information processing, which is consistent with the proposition that motivational forces shape cognition (Kruglanski, 1996). The synthesis of motivation and cognition has been studied by consumer researchers from different perspectives, and it has been shown, for example, that motivation can affect all stages of information processing, including stimulus encoding, storage, and retrieval (D. M. Bartels & Johnson, 2015). The impact of goal pursuit on information processing and perception is also well documented in psychology literature, suggesting that highly accessible goal constructs provide 'orienting value', which guides the viewer's attention automatically to the relevant stimuli in the environment (Bruner, 1957; Huang & Bargh, 2014; Roskos-Ewoldsen & Fazio, 1992). For example, inattentional blindness research has demonstrated that salient and unusual events can be missed entirely when individuals are occupied with a certain goal pursuit (Mack, 2003; Simons & Chabris, 1999). In line with studies on motivated perceptual interpretation of events (Kunda, 1990), it has also been shown that goal-facilitating objects can appear more accessible to the viewer – closer in distance (Balcetis & Dunning, 2010) and larger in size (Veltkamp, Aarts, & Custers, 2008).

Thus, consumers' attention and perception are highly influenced by the motivational processes, but as argued by Zadra and Clore (2011), also emotions routinely affect how and what humans see- having an impact on early visual processes, perceptions of natural environments, global versus local perceptual focus and susceptibility to visual illusions. According to this account, emotions regulate visual perception and provide embodied information about the opportunities for and costs of acting on the environment (Zadra & Clore, 2011). For example, studies have shown that if people are fatigued, in poor physical condition, or anticipating greater effort, they perceive hills to be steeper (Bhalla & Proffitt, 1999; Proffitt, Bhalla, Gossweiler, & Midgett, 1995). This indicates that a system relying on emotions and bodily states modulates perception in order to support decisions about anticipated actions, as '*vision evolved to support survival rather than to provide a geometrically accurate picture of the environment*' (Zadra & Clore, 2011, p. 682). Also in the domain of consumer research, various models have been built on the idea that consumers use affect as a heuristic, which has an impact on their perceptions and evaluations of the objects in the marketplace. According to 'affect-as-information' hypothesis, introduced by Schwartz and Clore (1983), positive and negative affective states have congruent effects on evaluations of objects.

Thus, motivational and emotional processes have an impact on both, selective attention, by preparing the visual system to detect relevant aspects of the environment easier (Bruner & Postman, 1947; Veltkamp et al., 2008), as well as on perception, by supporting decisions that are related to anticipated action. Again, it's not a unidirectional link. The mere perception of emotionally evocative stimuli may trigger emotional responses, whereas some stimuli require more cognitive interpretation than others (Zadra & Clore, 2011). Furthermore, numerous studies have shown that both consciously and unconsciously perceived stimuli can trigger goal pursuit and affect behavior (Bargh & Chartrand, 1999; Custers & Aarts, 2005; Dijksterhuis & Bargh, 2001)- a phenomenon that also applies to consumer behavior (Bargh, 2002; Chartrand et al., 2008; Dijksterhuis, Smith, & Baaren, 2005; Fitzsimons et al., 2002). This implies that situational variables and external influences, by evoking motivational and affective processes, can instigate higher mental processes involved in information processing and behavior, and do so in an automatic and implicit fashion, bypassing conscious awareness (Bargh, 2007; Huang & Bargh, 2014). In the context of consumer research, or social science research in general, this indicates that external variables, including the study setting, can have a significant impact on how individuals process information and behave.

In naturalistic settings information processing and behavior are to a large degree driven by automatic processes and affective responses that occur fast and often outside conscious awareness (Bargh, 2002; Camerer et al., 2005). Not only are consumers in retail settings exposed to a large number of marketing stimuli, but also atmospheric cues have been shown to have a robust influence on shoppers' emotions, evaluations and behavior (Sherman et al., 1997; Turley & Milliman, 2000; Xiao & Nicholson, 2013). Studies in artificial laboratory setups, in contrast, often fail to resemble real-life consumption situations. Accordingly, contextual replications have revealed that compared to highly controlled laboratory setups, the role played by deliberate conscious choice process diminishes significantly in naturalistic, noisy and complex environments (Bargh, 2002). This has ramifications on the generalizability of the findings from the lab to the outside world. Even though the aspect of external validity in consumer research has received considerable attention (Lynch Jr, 1982; Winer, 1999), a very limited number of studies have investigated the impact of the study setting on consumer information processing and choice behavior.

Consistent with the argumentation presented, consumer information processing can be considered as an interplay between motivation, affect and perception, and influenced by contextual variables. In the scope of this dissertation, the impact of contextual variables is investigated by exposing consumers to either simulated or real-life stimuli. Consumers' information processing in different contexts is studied by tracing and analyzing attentional processes that are manifest in the allocation of visual attention. This is achieved by employing eye-tracking methodology. The model of consumer information processing, as dependent on contextual variables, is presented in figure 4.

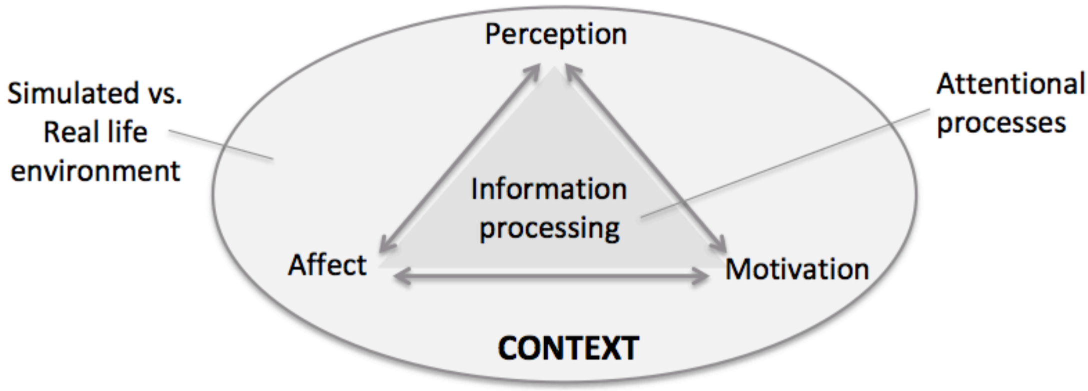

Figure 4: The model of consumer information processing, as dependent on contextual variables. This dissertation aims to assess the impact of contextual variables (simulated vs. real-life environment) on consumer attentional processes (manifest in the allocation of visual attention).

2.4 Eye-tracking in consumer research

As eye tracking research offers new ways of collecting data, framing research questions and investigating how humans view and experience the world (Tatler, 2014), eye-tracking methodology is becoming increasingly common in marketing research. Visual attention should not be considered merely as a gate through which information enters for higher-order cognitive processing, but a key coordinating mechanism in charge of maintaining information processing and other goals over time (LaBerge, 1995; Wedel & Pieters, 2008a). Thus, attention can be regarded as central to the processing and effectiveness of visual marketing stimuli.

Eye movements play the central role in visual processing and are regarded as an overt behavioral manifestation of the allocation of visual attention (Henderson & Ferreira, 2004), thereby offering crucial insights into understanding human behavior. Visual attention is inferred from patterns of eye movements, involving periods when the eye remains relatively stable – called fixations – and ballistic movements for redirecting the gaze – called saccades. Humans' ability to obtain high-resolution information from visual stimuli comes through the part of the eye called fovea, and attention selection involves bringing a stimulus area into the focus of attention by foveating on it (Holmqvist et al., 2011). The sampling of visual information is constrained by the spatial and temporal limits of the human eye, and at any given point in time, only about 8 percent of the visual field is projected on the fovea and available for detailed processing (Wedel & Pieters, 2008a). This implies that high acuity vision is a scarce resource, and must therefore be distributed optimally in the given situation. Locations selected for fixations during behavior provide insights into moment-to-moment information requirements, and eye movements, therefore, provide a powerful and objective measure of cognitive processes and information requirements (Tatler, 2014).

The degree to which external factors (relating to the stimulus properties) and internal factors (relating to the goals of the observer) influence eye movements has been the dominant theme in eye movement research for decades. Already in 1905, McAllister found that stimulus properties influence fixation behavior. The influence of low-level stimulus features has been modeled (Itti & Koch, 2000; Itti, Koch, & Niebur, 1998) and tested in numerous studies , but much of this research has shown that purely low-level accounts of fixation selection do a poor job in predicting human viewing behavior (Kowler, 2011; Tatler, 2007). With regards to internal factors, classic studies by Buswell (1935) and Yarbus (1965) were first to demonstrate that task instructions have an impact on the selection of fixation locations. Also more recent studies, especially when conducted in natural viewing conditions, suggest that the deployment of visual attention is guided more by the variables associated with the viewer's internal goals than by visual characteristics of the stimulus (Ballard & Hayhoe, 2009; Tatler, Hayhoe, Land, & Ballard, 2011). However, stimulus-driven and goal-oriented attention are generally closely intertwined, and indistinguishable when explaining the selection of fixation locations.

Eye-trackers sample the position of the eyes at a specific frequency (generally ranging from 30 to 1000Hz), and event detection algorithms detect oculomotor events, i.e fixations and saccades, based on specific criteria. The most common types of eye-trackers use infrared corneal reflection methodology, and the accuracy of their temporal and spatial resolution have made them suitable for academic and commercial applications in marketing (Wedel & Pieters, 2008a). The growth of eye-movement applications in marketing research can be attributed to rapid technological advancements – modern eye-tracking systems enable an unobtrusive measurement of eye movements in natural exposure conditions with short calibration times and at comparatively low costs (ibid.). Apart from stationary setups with screen-based stimulus display, mobile eye-tracking systems enable to trace viewers' attention in three-dimensional environments. Therefore it is possible to analyze consumers' information processing and behavior in naturalistic settings from the first-person perspective.

Even though the first eye movement analyses related to visual marketing can be traced back to the first half of the 20th century, it was not until Russo's article of 1978, "Eye-Fixations Can Save The World", that eye-tracking became an acknowledged method for assessing consumers' responses to marketing stimuli (Wedel & Pieters, 2008a). Thus far eye-tracking methodology has been applied to investigate consumer choice process and information processing in various conditions, and in relation to a number of different stimuli. This includes magazine advertisements (e.g. Pieters & Wedel, 2007), internet advertising (e.g. Drèze & Hussherr, 2003), television commercials (Janiszewski & Warlop, 1993), package designs (e.g. Clement, Kristensen, & Grønhaug, 2013; Husić-Mehmedović, Omeragić, Batagelj, & Kolar, 2017), brand choice (e.g. Pieters & Warlop, 1999) and supermarket shelving (e.g. Chandon, Hutchinson, Bradlow, & Young, 2009). Since it would not be feasible to list all studies and findings throughout decades of research work, only a brief review of some of the most relevant studies will be provided.

In line with the thesis that viewers' internal goals impact their eye movements (Yarbus, 1965), Pieters and Wedel (2007) studied the impact of information processing goals on advertisement viewing. Comparing the allocation of attention to four design elements, pictorial, brand, headline, and body, the authors confirmed that advertisement informativeness is goal contingent. For example, the goal to memorize an advertisement enhanced attention to the body text, pictorial and brand design elements. A brand learning goal, in contrast, enhanced attention to the body text, but simultaneously inhibited the attention to the pictorial design (Pieters & Wedel, 2007). It has been further confirmed that attention allocated to textual and pictorial elements of advertisements are influenced by viewers' goals (Rayner, Miller, & Rotello, 2008), and goal-related influence on visual attention also applies to visual decision making (Glaholt, Wu, & Reingold, 2010) and product choice (van der Laan, Papies, Hooge, & Smeets, 2017). Thus, visual attention in marketing is not merely a function of environmental, or extrinsic factors, but is greatly influenced by motivational, or intrinsic factors (Wedel & Pieters, 2008b).

Various studies have investigated the link between visual attention and product choice. One of the first studies on information acquisition during product choice was conducted by Russo and Leclerc (1994), where they used video recordings through a one-way mirror to capture the viewer's eye movements. Based on the first and last refixation on an alternative, the authors separated the decision period into three phases: orientation, evaluation, and verification (Russo & Leclerc, 1994). Employing screen-based eye-tracking, Pieters and Warlop (1999) studied how time pressure and motivation influence visual attention during brand choice. Their findings revealed that time pressure causes consumers to accelerate and change their scanning strategy, and high motivation results in increased attention to brand information (Pieters & Warlop, 1999). Chandon and colleagues (2009) employed a study design where viewers were seated in front of a large screen, exposing them to various product displays, and were instructed to verbally report the products that they consider and would choose for purchase. The authors found that the number of facings has a strong impact on evaluation that is mediated by its impact on visual attention. Further, top- and middle shelf positions attract the most attention, but only top-shelf positions carry through to brand evaluation (Chandon et al., 2009). Thus, eye-tracking can provide valuable insights in consumer information processing during decision-making process, but the external validity of the findings derived from artificial setups has received comparatively little attention.

A limited number of studies have also studied consumer visual attention and choice process in real-life shopping environments. Employing mobile eye-tracking in a supermarket, Clement (2007) proposed five distinct phases of in-store buying behavior. A later study by Clement and colleagues (2013), focusing on physical package features, found that shape and contrast dominate the initial phase of searching. The authors also found that the decision process was faster when the consumers were familiar with the store, but contrary to the expectations, consumers who reported being under time pressure used more time for the choice process (Clement et al., 2013). Gidlöf and colleagues (2017) investigated the interplay between consumer preferences and properties of product displays, and found that even after controlling for all internal and external factors, visual attention is the most important predictor when it comes to actual purchases. The authors also found that the number of facings has the largest impact on visual attention, but all other factors equal, products placed on the lower and upper shelves have a higher likelihood of being purchased. In a real-life shopping environment, consumers only attend approximately 40% of all choice alternatives, and a strong interaction between visual saliency and consumer preferences indicates that consumers use package saliency in their favor when it helps them to identify products that meet their needs (Gidlöf et al., 2017). Consumer decisions, therefore, are not only dependent on the properties of the choice alternatives but are influenced greatly by internal factors and the allocation of attention.

As evident from this brief review, consumer information processing and behavior is multi-faceted and dependent on numerous factors, whereas visual processes are fundamental in processing marketing related content, as well as in searching, evaluating and choosing products for consumption (Wedel & Pieters, 2008b). When consumers perceive their surroundings, for example, a retail environment, they are acting in order to gain information that helps them to perform the tasks they engage in. From that perspective, perception is not merely the passive reception of information but becomes an active part of how consumers operate in an environment (Tatler, 2014). Both, the processes of perception and action allow humans to build representations of the surrounding world, and as suggested by Hommel and colleagues (2001), perception and action are ‘functionally equivalent’. Eye movements can be regarded as having the role of coordinating perception and action (Tatler, 2014), and in consumer research, eye-tracking represents a method that allows to trace these processes objectively and unobtrusively also in naturalistic settings.

The bi-directional link between perception and action (which can be regarded as equivalent to the interplay between perception, motivation and affect, as proposed in the previous chapter), highlights the importance of considering the study setting as a factor influencing consumer visual attention and behavior. Unlike physical product displays in supermarkets, images displayed on a computer screen cannot be 'acted upon'. Thus, the perception of stimuli, as well as the cognitive processes accompanying a choice task may differ in artificial lab settings versus in noisy retail environments. In other words, before assuming external validity of laboratory-based findings, it is important to investigate the aspects in which the study setting influences consumer information processing and behavior. Further, Pham (2013) criticized the research on consumer psychology for lacking internal and external relevance and suggested that '*we should conduct and encourage more field studies with real consumers and real behavior*' (Pham, 2013, p. 422). By employing eye-tracking methodology, this dissertation aims to contribute to these issues, and also provide implications for both, academics and practitioners.

3. METHODOLOGY

3. Methodology

3.1 Scientific approach

Considering the research on human vision and the deductive nature of eye movement analysis, one would be inclined to categorize the studies applying eye-tracking methodology as empirical and positivist. However, in social sciences there are multiple views on what constitutes truth and genuine knowledge about phenomena. Regardless of the methodological orientation of this dissertation, the unit of analysis is considered to be the consumer, a social being whose responses and behavior are influenced by an infinite number of variables. Furthermore, the literature is clear that eye movements are strongly influenced by the semantic interpretation of the scene, i.e. top-down processing. Top-down factors are defined as reflective of the interplay between higher cognitive factors, such as the viewer's task, goals, and familiarity with similar types of scenes (Nyström & Holmqvist, 2008; Sarter, Givens, & Bruno, 2001), which introduces a high degree of subjectivity in the subject matter.

The review of paradigms in consumer research revealed a schism between positivist and postmodern approaches – a philosophical debate that many authors within social sciences have addressed. It is generally agreed that the philosophical paradigm dominating marketing inquiry has been logical empiricism (Anderson, 1983; Hunt, 1991; Peter & Olsen, 1983), however, since the 1980s many authors have promoted relativist perspectives in marketing science and argued for the importance of situational context, subjectivity of perception and the constructed nature of human reality (Rod, 2009). Contrasting realist and relativist views in marketing science, Peter (1992) proposes that the former results in traditional empirical research, whereas the latter is better suited to develop, rather than test theories, implying that from a methodological standpoint there might exist some complementarities. Weick (1999), in contrast, argues that the image of paradigm "wars" has the connotation that the path to victory lies in monologues that overwhelm, rather than dialogues that reconcile, and, adopting a pragmatic position, he recommends researchers to "drop their heavy tools of paradigms" (Weick, 1999). However, based on an investigation of incommensurability of positivist and interpretivist approaches, Davies and Fitchett (2005) state that:

> *"A misplaced reading of paradigm incommensurability has resulted in research practices appearing oppositional and static when they are essentially undifferentiated and dynamic. An over-socialised research epistemology has raised the tangible outcomes of research activities to be dominant in directing research practice."* (Davies & Fitchett, 2005, p. 272)

Thus, it is evident that the schism between positivist and postmodern approaches is a challenge that researchers, in their attempt to advance marketing science, must not overlook. It is important not to marginalize potential contribution and diversity among academic sub-communities, but also between academics and industry practitioners (Davies & Fitchett, 2005). Accordingly, the debate should not result in an "either/or" situation, as no one philosophical perspective should have a monopoly determining what constitutes a useful contribution to our understanding of marketing phenomena (Anukam, 2015). Instead, researchers "*should be able to go beyond objectivism and relativism, employ practical, rational, communal discourse in an effort to explain phenomena*"(Rod, 2009, p. 126).

Researchers and scholars of social sciences adopt often implicitly one of three metatheories (Fleetwood, 2005): positivism, postmodernism or critical realism.
Whereas positivists see the social world as a closed system with readily observable cause-effect relations (Sousa, 2010), postmodern perspective regards reality as multiple and relative (Hudson & Ozanne, 1988). These multiple realities are seen as dependent on other systems for meanings, (Lincoln & Guba, 1985; Neuman, 2000), indicating that knowledge is not objectively determined, but instead socially constructed (Carson, Gilmore, Perry, & Gronhaug, 2001) and perceived (Hudson & Ozanne, 1988). For critical realists the social world is an open system, which exists independently of any knowledge. According to this view, social science should be critical concerning the social world that it aims to tentatively describe and explain (Sousa, 2010).

For a theory of knowledge to be possible, any investigation must logically presuppose a metatheory that lies beyond any substantive theory, empirical research or human practice (Fleetwood & Ackroyd, 2004). Any research inevitably builds on a particular view related to the nature of reality (ontology), the relationship between the researcher and how the reality is captured or known (epistemology), what methods to use in an inquiry (methodology) and what are the underlying causes (etiology) (Sousa, 2010). Considering the multiple dimensions of this dissertation, including the subjectivity of perception, the importance of situational context as well as the deductive nature of eye movement analysis, neither positivism nor postmodernism seems appropriate. Contrary to the postmodern view, I do not find it reasonable to deny inference and rationality, but I also do not think that inquiries related to consumer research should be reduced to what is objectively observable. Rather than attempting to locate myself in the center of these paradigms (and thereby risking to duplicate the ontological problematic), I am guided by critical realist philosophy, which is predicated on epistemological and methodological pluralism, but ontological realism.

Critical realism entails a belief in ontological realism, epistemological relativism and judgmental rationalism (Bhaskar, 1986). According to this view, there are processes and entities in the world independently of human intervention, whereas the social world is neither voluntaristically produced by, nor reducible to, the thoughts or actions of individuals (Groff, 2004). Science is understood as practical research work, rather than scientific knowledge, and experiments are described as active interventions in reality, which necessitate systematic manipulation of events in order to obtain results (Danermark, Ekstrom, & Jakobsen, 2005). The idea behind scientific experiments is to bring about a particular constant conjunction of events in an artificial environment in order to obtain knowledge and make generalizing claims about the world outside the experimental setting (Groff, 2004). This claim presupposes that while researchers actively induce regularities, they do not produce the causes of such regularities, indicating that there has to be an ontological distinction between the empirical regularity and the causal law. Distinguishing between three ontological domains: the empirical, the actual and the real, the aim of the scientific work is seen as '*to investigate and identify relationships and non-relationships, respectively, between what we experience, what actually happens, and the underlying mechanisms that produce the events in the world*' (Bhaskar, 1978; Danermark et al., 2005, p. 21).

Epistemological relativism and judgmental rationalism in critical realism indicate that because all beliefs are socially produced, they are potentially fallible, but it is still possible to provide justifiable grounds for preferring one theory over another (Patomäki & Wight, 2000). In other words, research practice has to involve observation of events and it is essential to know the mechanisms that produce the empirical events. However, due to the deep dimension of reality, these observations cannot be reduced to observations of phenomena at the empirical level, and the knowledge we attain is always fallible and with varying usefulness in different conditions (Danermark et al., 2005). Theories are therefore the transitive objects of science that indirectly connect science with reality, but can only be regarded as the best truth about reality for the moment. Furthermore, research should be guided by theory and not be subordinate to specific methodological rules. It is the nature of the subject of study that determines what research methods are suitable, and what kind of knowledge it is possible to obtain about different phenomena. This, in turn, has an impact on the importance of methodologies, and more specifically, how different methodologies can convey knowledge about generative mechanisms (ibid.).

Apart from the methodological aspects related to the design of eye-tracking studies and data visualization, the main theoretical and empirical inquiries in this dissertation involve consumer responses and behavior in different study environments. Differential psychological effects of the study settings on human behavior have been documented in various fields of research, but differences in information acquisition and processing have not received much attention in consumer research literature. As humans acquire a great majority of sensory information through vision, it is methodologically appropriate to employ eye-tracking methodology and conduct experiments to trace the allocation of visual attention, which in turn can be considered as reflective of mental processes. Thus, as it has been suggested that the impact of cognitive deliberation on consumer behavior is significantly reduced in naturalistic settings compared to artificial laboratory settings (Bargh, 2002), it is reasonable to investigate visual attention in order to be able to explain the mechanisms underlying this phenomenon.

Following the critical realist philosophy, human vision and its development in conjunction with various mental processes throughout the course of human evolutionary history, as well as the measures allocated to eye movements constitute a reality that exists in objective terms. However, the degree to which the study setting impacts an individual, as well as the semantic perception of various scenes are variables that are highly subjective. The meaning that is associated with consumers' perception of visual scenes, or of the environment, emerges through socio-cultural relations, indicating that absolute certainty is impossible to attain. However, an investigation of visual attention in different settings provides insights related to the potential mechanisms at work, thereby contributing to the discussion of why such differences may occur.

3.2 Methodology for the articles

All three articles are based on the analysis of eye-tracking data and rely on quantitative measures of eye movements. However, the suggested explanations and interpretations of patterns of gaze allocation often draw on models that have a component of qualitative assessment. It is widely acknowledged that fixation selection depends on both intrinsic and extrinsic factors. While it is possible to provide objective measures related to the visual properties of the stimuli, the intrinsic factors, including the viewer's goals, semantic interpretation, and familiarity with similar types of scenes, are variables that are difficult to assess objectively. Furthermore, just as there are differences in personality traits, there are also inherent differences in manners in which consumers process information and make decisions. Thus, rather than treating consumer visual attention as a deterministic and systematically quantifiable phenomenon, this dissertation acknowledges the element of subjectivity in responses to visual stimuli, but applies deductive approaches to investigate the mechanisms that underlie information processing in different environmental contexts.

In order to investigate the patterns of consumer information processing in different settings, Article 1 focuses on the comparison of voluntary spontaneous visual attention to stimuli presented in their physical form versus as screen images. The experiments are based on free-viewing paradigm where respondents are exposed to different stimuli for a fixed period of time, and the data analysis is concerned with differences in the spatial distribution of gaze. Whereas study 1 employs within-subject design and investigates the distribution of gaze locations to stimuli in varying scales (product display, banners), study 2 is based on between-subject design where stimulus dimensions in two conditions are kept constant (package designs).

The empirical study in Article 2 is based on between-subject design and compares consumer choice process when (1) exposed to a screen image of a product display, (2) interacting with mock shelves in the lab, or (3) completing a shopping trip in a real-life supermarket. Consumer choice behavior in the three settings is compared with regards to the decision time and proportion of alternatives attended, as well as the proportion of visual attention allocated to the chosen item, to the choice alternative located in the center of the display, to different shelf levels, and to choice alternatives with different number of facings.

Article 3 has a more methodological orientation and argues that due to variations in consumers' viewing angle and distance from the stimulus in three-dimensional environments, it is not valid to treat the gaze points as equal when constructing Gaussian-based heatmaps for data visualization. In line with these arguments, the article proposes a novel method for constructing three-dimensional heatmaps that take the viewers' distance and viewing angle into account.

3.3 Delimitations

The empirical studies included in this dissertation only investigate consumer visual attention to fast moving consumer goods (FMCG) category. This category involves low-risk low-involvement goods where individual preferences and experiences, as well as both hedonic and utilitarian motivations, may impact visual behavior. The degree to which the attentional processes may differ for other product categories, such as consumer durables, is not discussed. As the goods used as stimuli do not vary significantly with regards to their price, and because cognitive processes related to value estimation are beyond the scope of this research, the impact of products' price is not included in the analyses.

The two first articles are based on contextual manipulations, i.e. the exposure to stimuli as screen images versus in their physical form, and choice process in three different experimental setups. The experimental setups in the second article include various confounding factors and a detailed discussion of the limitations of the study is provided in the paper.

Even though a limited amount of information about participants' consumption habits and preferences was collected, no self-reported measures were included in the analysis. It was based on the consideration that limited verbal declarations would not be sufficient to explain the allocation of visual attention on various choice alternatives, and such explanations would not be reasonable considering the small study samples and large between-subject variability of visual behavior.

Thus, the empirical studies are solely based on eye-tracking methodology and focus on the allocation of visual attention to various stimuli. The first two articles analyze the spatial distribution of fixations over time in relation to different areas of interest (AOIs). The third article proposes a method for constructing three-dimensional heatmaps based on raw gaze points. The studies do not focus on the sequence in which the stimulus elements are attended, i.e. scan paths, and also measures such as saccade length or pupil dilation are left out from the analysis. Furthermore, no other psychophysiological techniques, such as electrodermal activity or electroencephalography are covered.

The theoretical background and explanations are mainly based on theories of consumer behavior and vision research but draw also on findings from social and cognitive psychology. Even though some aspects of neuroscientific underpinnings of attentional mechanisms and anatomical aspects of human vision are mentioned, these topics are not discussed in depth. The primary focus of this dissertation is on consumer information processing, and more specifically, on consumer visual attention and the insights that eye-tracking methodology can provide in the field of consumer research.

4. ARTICLES

4. Articles

4.1 Computer screen or real life: Comparing the allocation of visual attention in remote and mobile settings

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To be submitted to: Journal of Consumer Research

Abstract:

In the realm of consumer research, it is vital to understand how consumers process information and attend visual stimuli. However, studies employing eye-tracking generally rely on stationary setups where stimuli are compressed into two-dimensional screen-images. Thus, there is ambiguity related to the generalizability of the results from screen-based studies to viewing behavior in a three-dimensional world. Employing the free-viewing paradigm, we ran two studies to investigate the differences in the allocation of visual attention to stimuli presented as screen-images versus in their physical form. The findings revealed systematic differences in how participants view marketing stimuli in the two conditions: (1) when exposed to the large marketing-related stimuli in their physical form, there is decreased attention to the lower visual field and the fixations are less spread out, and (2) when exposed to physical packages, viewers pay more attention to the pictorial element, rather than textual information, and exhibit slower screening of the design elements. Thus, demonstrating that the stimulus display method has an important impact on the viewers' visual behavior, the findings call for caution when generalizing findings from screen-based eye-tracking studies to real-life settings.

Key words: eye-tracking, consumer behavior, information processing, external validity

1. Introduction

As eye tracking research offers new ways of collecting data, framing research questions and investigating how humans view and experience the world (Tatler, 2014), eye-tracking methodology is becoming increasingly common in marketing research. In the realm of marketing and consumer research, it is vital to understand and be able to predict how consumers process information and how that leads to downstream effects, such as memory formation, consideration, and choice.

Applied to visual marketing, eye-tracking has provided valuable insights in areas such as product and brand choice (Pieters & Warlop, 1999; Russo & Leclerc, 1994), point-of-purchase marketing (Chandon, Hutchinson, & Young, 2002), print advertising (Wedel & Pieters, 2000), television commercials (Aoki & Itoh, 2000), and web design (Drèze & Hussherr, 2003). However, the majority of such studies are conducted in controlled lab environments with screen-display of stimuli, which often bear little resemblance to the three-dimensional world where these objects are normally encountered. While the screen-based setting is suitable for investigating some research questions, especially related to web design and online shopping, there is ambiguity related to whether and to which degree the findings from screen-based studies can be generalized to the viewing behavior in a three-dimensional world.

To our knowledge no eye-tracking studies have investigated the differences between how people view marketing stimuli such as product displays, advertising banners, and package designs when exposed to a screen image versus in their physical form. The objective of this study is therefore to compare and identify differences in the allocation of visual attention in these two conditions. We provide a brief theoretical account on what drives gaze allocation and how visual behavior differs when comparing screen-viewing and real-life settings. Next, we present two studies where participants are exposed to identical marketing-related stimuli in both screen-based and physical display conditions, and pinpoint differences in gaze allocation, thereby demonstrating the importance of considering contextual cues and physical realism in eye-tracking studies. Also, implications for researchers and practitioners together with recommendations for further research are provided.

2. Drivers of visual attention

Within the last few decades eye-tracking research has gone through rapid development, spread to numerous disciplines and gained popularity both in academia and in practice. Eye-movements are regarded as an overt behavioral manifestation of information acquisition and sensory processing (Henderson & Ferreira, 2004), and accordingly, eye-tracking research has become an invaluable method for studying spatio-temporal dynamics of attention. Attention selection involves moving the eyes so that light from the object of interest falls directly on the fovea, a small area at the back of the eye that provides sharp central vision. Information acquisition takes place primarily during fixations, i.e. short time periods when the eye remains relatively stable. These are accompanied by saccadic eye movements that occur several times each second and are supported by covert attention from peripheral vision, helping to guide the selection of fixation locations (e.g. Duchowski, 2007; Holmqvist et al., 2011; Tatler, 2009).

There is a considerable amount of ambiguity when it comes to the constructs and models describing and predicting the guidance of visual attention. The degree to which external factors (relating to the stimulus properties) and internal factors (relating to the goals of the observer) influence eye movements has been the dominant theme in eye movement research for decades. Already in 1905, McAllister found that stimulus properties influence fixation behavior (McAllister, 1905), paving the way for the Saliency map hypothesis, proposing that relative conspicuity of features allows to predict how viewers allocate visual attention to a stimulus (Itti & Koch, 2000; Itti, Koch, & Niebur, 1998). A great amount of eye-tracking studies have applied the Saliency Map model to various setting and tasks, including brand search (van der Lans, Pieters, & Wedel, 2008) and consumer choice process (Gidlöf, Anikin, Lingonblad, & Wallin, 2017; Milosavljevic, Navalpakkam, Koch, & Rangel, 2012). While some studies have found that saliency-based models predict gaze guidance well above chance (e.g.

Carmi & Itti, 2006; Parkhurst, Law, & Niebur, 2002), much of this research has demonstrated the inadequacy of purely low-level accounts of fixation selection in predicting human visual attention (Kowler, 2011; Tatler, 2007), especially for real-world scenes and when the behavioral task is varied (Foulsham & Underwood, 2008; Henderson, Brockmole, Castelhano, & Mack, 2007; Tatler, Hayhoe, Land, & Ballard, 2011).

It has been proposed that stimulus-driven bottom-up attention has the highest impact during the early phases of the viewing process (Carmi & Itti, 2006; Parkhurst et al., 2002; van Zoest, Donk, & Theeuwes, 2004), and studying consumer in-store visual perception, Clement, Kristensen and Grønhaug(2013) found that the initial phase of searching was dominated by physical design features such as shape and contrast. However, researchers focusing on the impact of semantic content have proven otherwise. Nystrom and Holmqvist (2008) showed that over the entire course of viewing, fixation selection is guided by semantic informativeness of regions. Viewers' initial fixations landed on areas rated as semantically important, such as faces, even when they were reduced in contrast and had low contrast and edge density (Nyström & Holmqvist, 2008). Henderson and Hayes (2017) took it a step further, demonstrating that both meaning and salience predicted the distribution of attention. However, when the relationship between salience and meaning were controlled, only meaning accounted for unique variation in attention – a pattern that was evident from the very earliest moments of viewing (Henderson & Hayes, 2017).

The importance of semantic content in gaze guidance is also in line with neuroscientific findings. Gottlieb and colleagues (2014) posit that visual salience is encoded in the lateral intraparietal area of the brain associated with novelty and reward. From that perspective, value considerations and uncertainty or the need to acquire new information make up the two central factors that guide the distribution of attention (Gottlieb, Hayhoe, Hikosaka, & Rangel, 2014). Also Henderson and Ferreira (2004) took a viewer-centric approach, proposing that the factors influencing where viewers look in a scene include short- and long-term episodic scene knowledge, scene schema knowledge and task knowledge

(Henderson & Ferreira, 2004). This implies that gaze guidance cannot be solely attributed to stimulus-based factors, but is instead strongly influenced by the individual's semantic interpretation of the scene. It is also referred to as top-down processing and can be considered as reflective of the interplay between higher cognitive factors such as a viewer's task, goals, and familiarity with similar types of scenes (Nyström & Holmqvist, 2008; Sarter, Givens, & Bruno, 2001).

The role of cognition in directing gaze has been recognized since the classic studies by Buswell(1935) and Yarbus (1965), which demonstrated that task instructions have a great impact on fixation locations. Research in the domain of marketing has also shown that different processing goals have an impact on how consumers view advertisements (Pieters & Wedel, 2007), and priming of health goals causes consumers to gaze more at healthy choice alternatives, which in turn mediates the effect on choices (van der Laan, Papies, Hooge, & Smeets, 2017). In line with that, Gottlieb and colleagues (2014) propose that the key role of the gaze is to sample information to assist ongoing activities and to choose targets to reduce uncertainty about task-relevant information. Investigating the role of task in gaze control, Ballard and Hayhoe (2009) conclude that almost all behavior is goal oriented and the object of these goals translates into constellations of image features. In other words, the findings suggest that the deployment of visual attention is guided more by the variables associated with the viewer's internal goals than by the visual characteristics of the stimulus.

Apart from various viewing tasks and processing goals, studies on visual attention often employ the free-viewing paradigm. Even though the explorative natural viewing behavior can be regarded as reflective of the allocation of stimulus-driven bottom-up attention, in reality the impact of cognitive processes cannot be eliminated, and viewers simply choose their own agendas for scanning the stimulus (Ballard & Hayhoe, 2009; Tatler, Baddeley, & Gilchrist, 2005; Tatler et al., 2011). However, various eye-tracking studies focusing on visual marketing have employed designs where participants are instructed to screen through marketing stimuli as if they would do '*at home or in a waiting room*' (Janiszewski, 1998; Leven, 1991; Pieters & Wedel, 2004; Pieters, Wedel, & Zhang, 2007; Rosbergen, Pieters, & Wedel, 1997; Wedel & Pieters, 2000). Even if such natural viewing behavior involves a subjective agenda, viewers are likely to pay more attention to the stimulus areas that are informative and in compliance with their mental states, experiences, habits and the contextual environment. Thus, the free-viewing paradigm allows to gain an insight in unconstrained gaze guidance where the impact of feature-based factors is maximized and viewers are free to optimize the information acquisition given the novelty and reward value of different stimulus areas.

The above-listed evidence suggests that bottom-up and top-down processes in human viewing behavior are closely intertwined and indistinguishable when explaining the selection of fixation locations. All stimuli representing real-world scenes carry with them some semantic content, and even more abstract visualizations can trigger knowledge-based associations or expectations. Furthermore, as all viewing conditions comprise some goal, it may be more appropriate to study the distribution of gaze less as a function of bottom-up versus top-down processing, but instead regard it as a holistic mechanism influenced by stimulus characteristics, cognitive variables, oculomotor factors, and the environment or study setting. The impact of the context in which the study is conducted is frequently overlooked, but as more and more studies are moving out of the lab and into naturalistic settings, there is also an increasing interest in whether the lab-based findings can be generalized to real-world settings.

3. Screen-based vs. Real life viewing

Based on the proposition that perception and action are interdependent, it has been suggested that lab experiments with artificial stimuli and restrictions to participants' behavior lead to conditions where the interaction between perception and action differ from that found in real-world environments (Ladouce, Donaldson, Dudchenko, & Ietswaart, 2017). Accordingly, there is a considerable amount of research suggesting that the way humans view computer screen is different from their viewing behavior in naturalistic settings. To begin with, it has been shown that under natural viewing conditions, saccade amplitudes are much greater than when viewing a computer screen (Bahill, Adler, & Stark, 1975; M. Land, Mennie, & Rusted, 1999) and in unconstrained tasks these large gaze shifts are made with head movements (Stahl, 1999). Furthermore, it has been shown that fixation durations during real-life tasks have a wider range of durations and that fixations are temporally coordinated and sensitive to highly specific and subtle details about the task (Hayhoe, Shrivastava, Mruczek, & Pelz, 2003; M. Land et al., 1999). As the memory across fixations is limited, presumably due to the limited capacity of working memory (Irwin, 1996), such deployment of attention can be considered as reflective of the acquisition of information for motor planning and coordination (Ballard & Hayhoe, 2009; Hayhoe et al., 2003; M. F. Land, 2009). Indeed, in naturalistic settings the viewer is also an agent within the environment and can partly control the dynamics of the scene by moving around and interacting with objects (Smith & Mital, 2013). Stationary setups, in contrast, rarely allow participants to actively manipulate the objects in the environment. Considering the strong link between behavioral goals and overt visual attention during natural behavior, the principles governing saccade targeting decisions in screen-based viewing and real-life settings are likely to be different (Tatler et al., 2011).

Another important difference between the two settings is related to physical realism, which for screen-based display is significantly reduced. Namely, stimuli presented on the screen involve a limited field of view without any depth and motion cues, and the observer's viewpoint is fixed to the angle subtended by the display monitor (Tatler et al., 2011). Placing an image within the bounds of the computer monitor's frame therefore not only decreases its scale and limits its context, but also introduces strong biases in how the visual scene is viewed and processed. For example, it has been shown that large shopping displays facilitate faster search times than stimuli presented on a computer screen, as large displays are closer to physical reality and offer better utilization of peripheral vision (Tonkin, Duchowski, Kahue, Schiffgens, & Rischner, 2011). Peripheral vision supports directing consumer visual attention by helping to discriminate between products depending on whether they are relevant for the goal or not (Wästlund, Shams, & Otterbring, 2018).

It has also been shown that viewers have the tendency to fixate more at the center of the screen irrespective of the task or the distribution of visual features, probably reflecting a simple response to center the eye in its orbit, or representing a convenient location that makes the exploration of the scene more efficient (Tatler, 2007). While several studies based on screen-display of images have reported a strong central fixation bias (Bindemann, 2010; Foulsham & Underwood, 2008), studies investigating the allocation of visual attention to product displays in naturalistic environments have found the central fixation bias less robust in choice task (Gidlöf, Wallin, & Holmqvist, 2012) and not present in search task (Tonkin, Ouzts, & Duchowski, 2011). This difference in viewing behavior related to the central fixation bias in screen-viewing condition represents a strong argument suggesting that the display method has an impact on how viewers allocate visual attention to the stimulus.

Different studies have also investigated the differences in visual behavior in different settings. For example, a study by t'Hart and colleagues (2009) compared natural vision in outdoor environments with the visual behavior of participants who viewed the same video sequence from head-centered recordings. The study found that where people looked in a video predicted real-world gaze better than gaze allocation in static scenes, and that central bias was the strongest when isolated frames were presented randomly (T'Hart et al., 2009). Similar study design by Foulsham, Walker and Kingstone (2011) further revealed that viewing behavior in real-world involves selecting locations around the horizon with head movements, while eye movements remain more centralized and tend to stay fixated on a 'heading point' that is slightly above the center of the head frame-of-reference. In contrast, when a video of the same events was shown on the screen, participants shifted their gaze more often to the edge of the visual field (Foulsham, Walker, & Kingstone, 2011). These studies clearly demonstrate that visual attention is context dependent and not solely driven by visual features in the scene.

As the above-listed findings suggest, attributing fixation selection to merely bottom-up or top-down factors is overly simplistic and ignores aspects such as oculomotor biases, physical realism and the impact of the study setting. While great theoretical contributions are made in relation to how people view screen-displayed stimuli, several authors have expressed their concern related to the generalizability and applicability of the existing models to real-life environments (Lappi, 2016; Tatler, 2009). To better understand the impact of the study setting on viewing behavior, our objective is to test and reveal systematic differences in terms of how participants view the same visual stimuli in screen-based and three-dimensional viewing conditions. We chose to employ the free-viewing paradigm, as our main interest was to investigate unconstrained gaze guidance without an explicitly defined goal or task. In other words, we let the participants choose their own agendas for exploring the scene, thereby avoiding the impact of task description or subjective heuristics on fixation selection.

We approached the research question by running two empirical studies. The first study is based on a within-subject design and involves stimuli that in physical display condition have significantly larger dimensions, i.e. advertising banners and a product display. In the second study we employed a between-subject design and exposed participants to various package designs either as screen images or in their physical form, keeping the stimulus dimensions in two settings constant.

4. Study 1

4.1 Method

4.1.1 Participants

Prior to the study a large sample of participants filled in a pre-screening survey, screening for their category awareness, consumption habits, and demographic variables. In order to avoid memory-based effects, we only included participants who did not habitually consume the categories that were included as stimuli. A total of 51 participants in the proximity of a European university joined the experiment for the first viewing session and 20 of them returned for the second session[1] (15 female, mean age 26.75, st.dev 5.43).

4.1.2 Stimuli

During the physical display session the participants were exposed to a total of 5 stimuli displayed in randomized order: a mock-up shelf unit and 4 life-size banners. Out of these stimuli two advertisement banners (85x200 cm and 59x189 cm) and the shelf unit (270x193 cm) with 25 different variants and a total of 64 facings of morning cereal were considered as the critical stimuli.

During the screen-viewing session the participants were exposed to a total of 28 marketing related images. The stimuli included various images of product displays, advertisements, and package designs and were displayed in a randomized order. Out of these 28 screen-displayed stimuli, 5 images corresponded directly to stimuli that were shown in the physical display condition. The exposure time in both conditions was set to 6 seconds. The three critical stimuli together with the areas of interest are presented in figure 1.

Figure 1: Three critical stimuli and the areas of interest (AOIs). The allocation of attention on the product display is analyzed based on both the vertical scale (AOIs: Top, Middle, Bottom), as well as on the horizontal scale (AOIs: Left, Center, Right). The allocation of attention on advertising banners is analyzed based on the vertical scale (AOIs: Top, Middle, Bottom) as well as based on the design element (AOIs: Title, Text, Product, Pictorial).

[1] The reason for having such a low return rate is that the second session took place at minimum one month later during limited time windows and many of the participants could not be reached or fit the experiment session it in their schedule.

4.1.3 Procedure

The participants were randomly assigned to first partake either in the screen-viewing or physical display condition. To ensure that the memories of the previous experiment had sufficiently faded away, the participants were invited back for the second session in a different setting after a minimum of one month. Both viewing sessions were carried out in a lab at the university.

Upon arrival the participants signed the informed consent and received the instructions of the task in written form, where they were instructed to view the stimuli without any particular task in mind. It was followed by the calibration procedure, after which the experiment started. In screen-viewing condition the participants were seated at a table at approximately 62cm distance from the stationary eye-tracker. In the physical display viewing condition, similarly to the study design applied by Mack and Eckstein (2011), the participant was led into a dark laboratory room and instructed to stand at a specific position, marked with a luminescent marker on the floor located 150cm from the stimuli. Turning on the lights in the room marked the onset of the viewing period and after 6 seconds the lights were turned off again. The participant was then walked out of the room and the stimulus was changed. The same procedure was repeated for each of the stimuli.

Each session lasted approximately 10-15 minutes, and participants were awarded a goodie bag worth app. €20 for their participation. At the end of the second session the participants were also briefed about the aims of the study.

4.1.3 Eye movement recordings and data pre-processing

In screen-viewing condition the data was collected using Tobii T60XL eye-tracker (1920 x 1200, 60Hz). In mobile condition the eye movements were recorded using head-mounted Tobii 2 Pro mobile eye- tracking glasses with the sampling rate of 50 Hz /100 Hz and, screen camera of 1920 x 1080 with the resolution of 25 fps. All data were recorded and post-processed using iMotions biometric research platform versions 6.2 and 7.1.and later data analyses were carried out using SPSS 24.0 statistical software.

For the data collected in the mobile setting, iMotions automatic gaze mapping function was used for remapping the gaze points from video recordings to corresponding reference images. The gaze remapping was then manually checked frame by frame and corrections were made where necessary. For both conditions the fixation data was extracted using the default Tobii I-VT fixation detection algorithm with 30°/sec velocity threshold (Olsen, 2012; Tobii Technology, 2019). To substantiate the methodological approach, also Högberg, Shams and Wästlund (2018) and Laski and colleagues (2018) used Tobii Pro Glasses2 with Tobii I-VT Fixation filter for studying shoppers' visual attention in a supermarket environment. Meyerdig and Merz (2018) employed the same eye-tracker and fixation detection algorithm for studying consumers' attention to organic labels, and Miranda and colleagues (2018) employed the same approach for studying eye movements during reading from paper and various digital devices. The choice using fixation data is therefore based on the considerations that various prior studies have used the same approach and as the viewers' position relative to the static stimuli remained constant (thereby precluding smooth pursuits), the use of fixation data can be considered sufficiently reliable.

4.2 Results

4.2.1 Analysis based on TFD on different AOIs of the product display

To investigate the spatial differences in visual attention in screen-based versus three-dimensional viewing condition, we compared the attention allocated to different areas of three critical stimuli: a product display and two advertising banners (figure 1). The analyses were based on the metric total fixation duration (TFD), defined as the sum of all fixation durations in an area of interest (AOI).

As the first step, we investigated whether there are differences in the viewing time on different areas of cereal shelves in the vertical dimension[2]. We ran a General Linear Model (GLM) for repeated measures with Condition (Screen-viewing (2D), Physical display(3D)), AOI (Top, Middle, Bottom), and the

[2] Analyzing the data with regards to nine AOIs (accounting for both the horizontal and the vertical dimension) was not feasible due to the small sample of 20 participants and numerous cases where the participant never fixated on the AOI.

interaction between the two as model predictors. The data revealed a statistically significant interaction between the viewing condition and the AOI, F(2, 38)=3.95, p=.028. Pairwise comparisons with Bonferroni corrections were performed for statistically significant simple main effects. The main effect of the AOI was significant in the 3D condition F(3, 38)=8.36, p=.001, but not in the 2D condition F(2,38) =2.33, p=.11. There was no statistically significant difference in the attention allocated to the AOI Top in the two conditions, F(1, 19)=.46, p=.505. However, the viewing time for AOI Middle was significantly longer in the 2D condition (M=1810.23, 95% CI 1433.66 to 2186.79ms), compared to the 3D condition (M=943.97, 95% CI 636.98 to 1250.97ms), F(1, 19)=12.66, p=.002. The difference was also significant for the AOI Bottom, which was viewed significantly longer in the 2D condition (M=1142.80, 95% CI 777.47 to 1508.14ms) compared to the 3D condition (M=646.0, 95% CI 382.67 to 909.33ms), F(1, 19)=7.677, p=.012. The estimated mean values of TFD together with 95% confidence intervals in the two conditions are presented in figure 2.

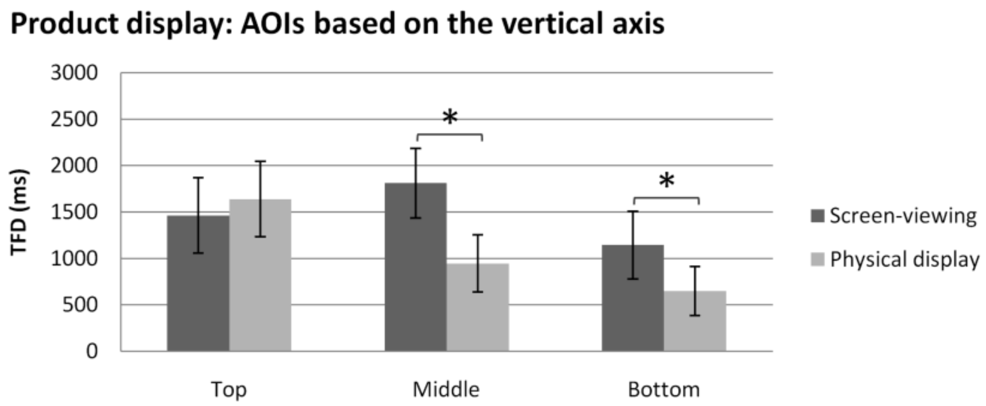

Figure 2: The estimated mean TFD values for the Top, Middle and Bottom areas of the product display in two viewing conditions. The error bars signify 95% confidence intervals and significant differences between the two viewing conditions are marked with an asterisk. The participants in the physical display condition attended the middle and bottom area of the shelf display significantly less than in the screen-viewing condition.

A similar procedure was carried out for investigating the allocation of gaze to the cereal shelves on the horizontal axis. Again, we and ran GLM for repeated measures with Condition (2D, 3D), AOI (Left, Center, Right), and the interaction between the two as model predictors. The two-way interaction between the condition and the AOI was not significant, F(2, 38)=2.72 , p=.079. Pairwise comparisons with Bonferroni corrections were performed for statistically significant simple main effects, revealing that the main effect of the AOI was significant both in the 2D condition $F(2, 38) = 10.28$, $p < .001$, as well as in the 3D condition $F(1.54, 29.3) = 34.24$, $p < .001$. Pairwise comparisons revealed that the viewing time for AOI Left was significantly longer in the 2D condition (M=1280.7, 95% CI 994.83 to 1566.58ms) than in the 3D condition (M=689.68, 95% CI 448.07 to 931.28ms), $F(1, 19) = 12.46$, $p = .002$. Also the TFD for AOI Right was viewed significantly longer in the 2D condition (M= 1022.83, 95% CI 743.41 to 1302.24ms) compared to the 3D condition (M= 376.8, 95% CI 176.36 to 577.24ms), $F(1, 19) = 19.75$, $p < .001$. For AOI Center the difference was not significant, $F(1,19) = .01$, $p = .93$. The estimated mean values of TFD together with 95% confidence intervals in the two conditions are presented in figure 3.

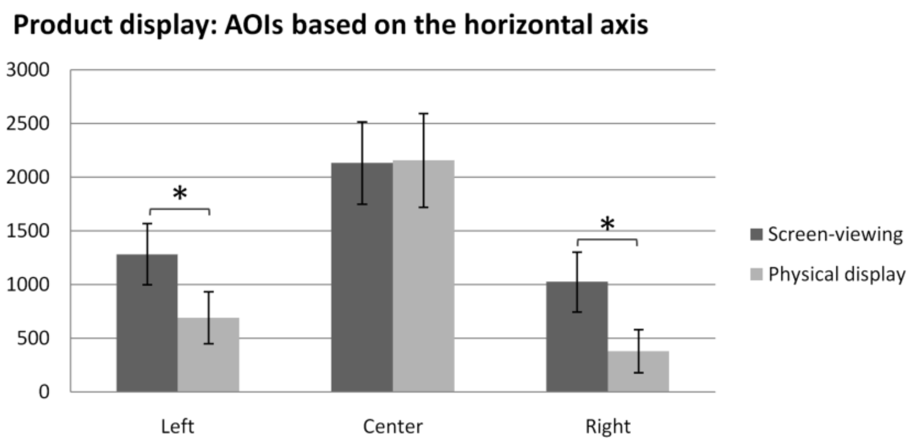

Figure 3: The estimated mean TFD values for the Left, Center and Right areas of the product display in two viewing conditions. The error bars signify 95% confidence intervals. Significant differences between the two viewing conditions are marked with an asterisk. The participants in the physical display condition attended the left and the right area of the shelf display for a significantly shorter time than in the screen-viewing condition.

4.2.2 Analysis based on TFD on different AOIs of the advertising banners

As the next step, the same type of analysis was run for the two advertising banners by dividing the stimulus area into three equally sized AOIs. Again, we ran a GLM for repeated measures with Condition (2D, 3D), AOI (Top, Middle, Bottom), and the interaction between the two as model predictors. For banner 1 (Innocent Smoothie), the two-way interaction between the condition and the AOI was significant, $F(2, 38) = 5.315$, $p = .009$. Comparisons were performed for statistically significant simple main effects with Bonferroni corrections. The main effect of the AOI was significant in the 2D condition F(2, 38) =13.86, p<.001, but not in the 3D condition F(2, 38)=.32, p=.727. The comparison of TFD in the two conditions revealed that the differences were not significant for AOIs Top and Middle. However, the AOI Bottom was viewed significantly longer in the 2D condition (M=2369.4, 95% CI 1966.93 to 2771.87ms) compared to the TFD in the 3D condition (M=1197.86, 95% CI 636.11 to 1759.61ms), F(1, 19)=12.92, p=.002.

For banner 2 (Benaday), the two-way interaction between condition and AOI was not significant, F(2, 38)=1.03, p=.367 and neither was the main effect of the viewing condition, F(1, 19)=.52, p=.479. However, the main effect of AOI showed a statistically significant difference in TFD both in 2D condition, F(2,38) =97.13, p<.001, as well as in 3D condition, F(2,38) =35.31, p<.001. The estimated mean values of TFD together with 95% confidence intervals in the two conditions are presented in figure 4.

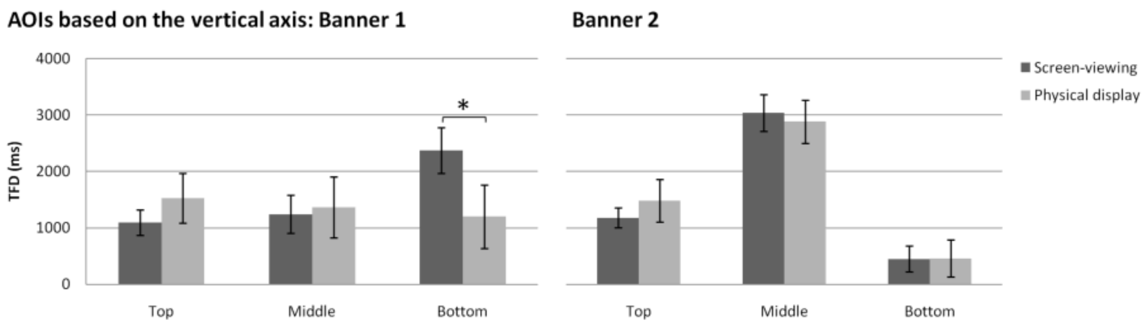

Figure 4: The estimated mean TFD values for the Top, Middle and Bottom areas of the two banners in the two viewing conditions. The darker grey signifies the screen-viewing and the lighter grey the physical display condition. The error bars signify 95% confidence intervals and significant differences between the two viewing conditions are marked with an asterisk. On banner 1 (Innocent smoothie) the bottom area was attended significantly longer in the screen-viewing condition than in the physical display condition.

Since the areas of interest in eye-tracking studies are generally based on the content of the design elements, rather than the visual field on the vertical axis, we also investigated the differences in attention allocated to different design elements. As visualized in figure 1, on Banner 1 (Innocent smoothie) three content-based AOIs were defined: Title, Pictorial and Product. Again, we ran a GLM for repeated measures with Condition, AOI, and the interaction between the two as model predictors and total fixation duration (TFD) as the dependent variable. The data revealed a statistically significant two-way interaction between Condition and AOI, $F(2, 38)=8.41$, $p=.001$. Pairwise comparisons with Bonferroni corrections revealed that the main effect of the AOI was significant both in screen-viewing condition $F(1.35, 25.6) =88.86$, $p<.001$ as well as in physical display condition $F(2, 38)=8,37$, $p=.001$. While there were no significant differences in viewing time for AOIs Title and Pictorial, the AOI Product was viewed significantly longer in the 2D condition (M= 2794.65, 95% CI 2395.91 to 3193.39ms) compared to the 3D condition (M= 1849.81, 95% CI 1298.35 to 2401.27ms), $F(1, 19)=12.17$, $p=.002$.

The same procedure was repeated for banner 2 (Benaday) where the analysis was based on four AOIs: Title, Text, Product, and Pictorial. Greenhouse-Geisser correction was applied in cases where the Mauchly's test of sphericity indicated a violation of the spericity assumption. There was no statistically significant two-way interaction between the Condition and AOI, $F(2.13, 40.47)=.50$, $p=.62$. Post-hoc comparisons with Bonferroni corrections revealed that the main effect of the AOI was significant in 2D condition $F(3, 57) =20.57$, $p<.001$ but not 3D condition $F(2.05, 39.02)=3.35$, $p=.044$. Pairwise comparison of the TFD for different AOIs in the two viewing conditions showed no significant differences. The estimated marginal means with 95% confidence intervals are visualized in figure 5.

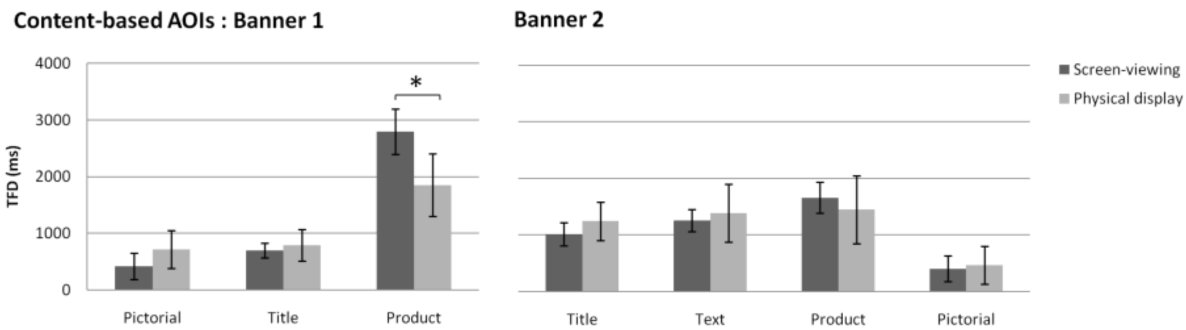

Figure 5: The estimated mean TFD values for different content-based AOIs for the two banners in the two viewing conditions. The error bars signify 95% confidence intervals and significant differences between the two viewing conditions are marked with an asterisk. On banner 1 (Innocent smoothie) the AOI Product was attended significantly longer in the screen-viewing condition than in the physical display condition.

4.3 Discussion of the Findings

In order to investigate the impact of the study setting on viewing behavior, we employed the free-viewing paradigm and exposed the same participants to identical stimuli displayed on the screen as well as in their physical form. As the exposure time was set to 6 seconds, the participants only had the time to briefly scan each stimulus. Since there was no specific viewing task introduced, it is assumed that the impact of the stimulus-related factors on in guiding gaze was maximized and the allocation of attention to the stimuli can be considered as reflective of the viewing patterns specific to the contextual conditions. It must be noted that the dimensions of the stimuli in the two viewing conditions differed markedly, implying that there were large differences in terms of the area of the visual field that the stimuli occupied.

When analyzing the allocation of attention to the product display, we found that the middle and bottom areas of the display were gazed more in the screen-viewing condition than in the physical display condition. Also the left and the right areas of the product display received more attention in the screen-based viewing condition than in the physical display condition. Increased attention to the bottom, left and right areas of the stimulus in the screen-viewing condition suggests that when the stimulus is compressed and presented as a screen image, the fixations tend to be more spread out across the stimulus area. The difference in the spread of the fixation locations can likely be attributed to the differences in the stimulus dimensions, as screening of a large stimulus area requires head movements that occur slower than eye movements.

This result is in line with the findings by Foulsham, Walker and Kingstone (2011), who found that compared to real-life viewing condition, screen-based display of the events caused the participants to shift their gaze more often to the edge of the visual field. Furthermore, the authors also found that viewing behavior in real-world settings involves selecting locations around the horizon with head movements, while eye movements remain more centralized and tend to stay fixated slightly above the center of the head frame-of-reference (Foulsham et al., 2011). The study presented here also found that unlike in screen-viewing condition where the center of the stimulus was gazed the longest, likely reflecting the central fixation bias (Tatler, 2007), the participants in the physical display condition allocated most attention to the upper center area of the display. The probable explanation here is that the upper center area of the product display was at the center of their visual field as the participants were standing and facing the display.

The allocation of attention to the two advertising banners was analyzed separately as they only featured limited information and had a different spatial placement of semantically informative design elements. On the first banner, Innocent smoothie, the majority of the textual information about the product was located at the lower part of the banner. Similarly to the display of cereal products, participants allocated significantly longer attention to the lower part of the stimulus area in the screen-viewing condition than in the physical viewing condition. When comparing the viewing time on different content-based areas of interest, the data revealed that the AOI Product received significantly more attention in the screen-based condition than in the physical display condition. On the second banner (Benaday), in contrast, a large part of textual information was presented in the middle area of the banner and the viewing condition had no significant impact on the allocation of attention. From these results it can be inferred that when large scenes are compressed into small screen-images, the screen-based study setting may lead to findings that cannot be generalized to physical settings, as in physical display condition viewers tend to allocate less attention to areas lower in the vertical dimension.

The differences in fixation locations clearly demonstrate that visual attention allocated to a scene is not solely driven by visual features, but depends on the stimulus presentation method. As the respondents in the two conditions were the same, the differences cannot be attributed to individual viewing behavior. However, as the stimulus dimensions in the two viewing conditions differed markedly, the differences in gaze behavior are likely to reflect the effect of the differences in the stimulus size, rather than the effect of a two-dimensional versus a three-dimensional scene. To test whether a three-dimensional scene is attended differently from a screen-image, we ran a second study where we kept the stimulus dimensions and other variables related to the visual scene constant and only manipulated the stimulus presentation method.

5. Study 2

5.1 Method

5.1.1 Participants

A total of 63 participants (28 female, mean age 24.49 (St.dev 5.15)) were recruited in the capital area. They were randomly assigned to one of the two study groups – either screen-based or physical display condition. Due to poor data quality we had to exclude the data from 7 participants, leaving us with a total of 56 participants (29 in screen-viewing and 27 in mobile condition). The experiment lasted app. 15 minutes and the participants were awarded snacks and beverages for their participation.

5.1.2 Stimuli

In both viewing conditions the participants were exposed to a total of 20 stimuli, 5 packages of morning cereal and 15 packages of tea. In physical display condition the packages were placed on a stool covered with a white cloth in front of a white background and located at eye height of the participant. For the screen-viewing condition we used an 8mpx camera to take photos of the individual stimuli in the exact same setup. The stimulus dimensions in the two conditions were kept as similar as possible, with the mean variation in package height of 1.05%, (St.dev 0.80). Figure 6 visualizes the stimulus presentation method in the two conditions.

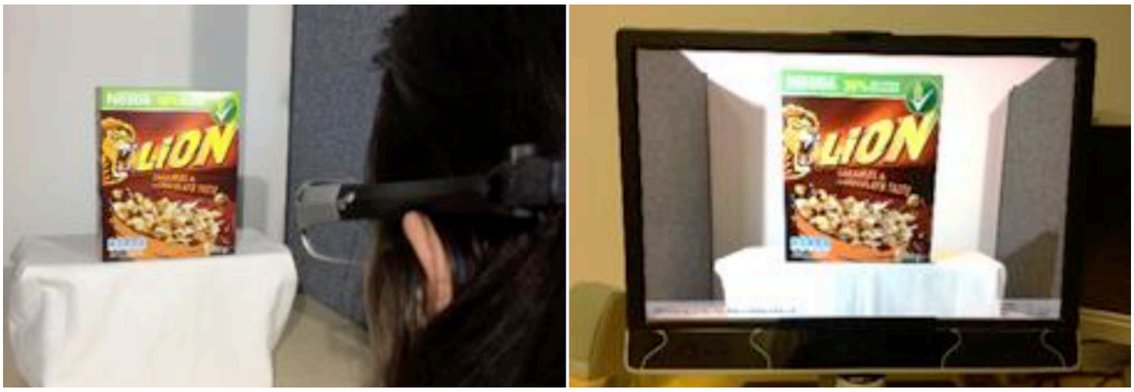

Figure 6: Display of stimuli in the two settings: physical display (left) and screen-viewing condition (right). In both conditions the stimulus dimensions were kept constant and the participants were seated at a distance of 62cm from the stimuli.

For the analysis we included 15 packages with clearly distinguishable areas of interest – 5 packages of morning cereal, 5 variants of tea in cylindrical packages and 5 variants of tea in rectangular prism packages. We distinguished between 4 design elements that were regarded as separate AOIs: Brand, Product name, Pictorial, and Text. An example of different package types and areas of interest are visualized in figure 7.

Figure 7: Examples of package designs from three categories: Cereal, Cylindrical tea packages and Rectangular tea packages. On all packages 4 types of areas of interest were defined: Brand, Product name, Text and Pictorial.

5.1.3 Procedure

The participants were randomly assigned to either the screen-viewing or physical display condition. Upon arrival the participants received the instructions of the task in written form and signed the informed consent. The participants were instructed to view the stimuli without any particular task in mind, but were kept naïve about the product categories or the purpose of the study. The experiment in both viewing conditions started with gaze calibration, which was followed by the exposure to stimuli in randomized order. However, based on the consideration that participants may be confused about the experiment at the beginning of the session, the first package was always kept the same and was not included in the analysis.

In both conditions the participants were seated at 62cm distance from the stimulus display. The participants were exposed to each stimulus for 8 seconds with 7-second intervals between the stimuli. In the screen-viewing condition the participants viewed the stimuli as screen-images and in between the stimuli they were exposed to a white screen. Similarly to the study design applied by Belardinelly and colleagues (2016), in the physical display viewing condition a big white cardboard (70x100cm) was used to block the view. While one experimenter lifted the cardboard between the participant and the stimulus display, another experimenter was behind a screen and changed the items displayed on the stand.

5.1.4 Eye Movement Recording

Similarly to study 1, the data for the physical display condition was collected using Tobii 2 Pro glasses, (50 / 100 Hz) and for screen-viewing condition, Tobii T60XL eye-tracker (1920 x 1080, 60Hz) was used. All data was recorded and post-processed using iMotions biometric research platform version 6.2/ 7.1 and fixations were extracted using Velocity-Threshold Identification (I-VT) algorithm with 30°/sec velocity threshold. All data analysis was performed using IBM SPSS 24 statistics software.

5.2 Results

5.2.1 Analysis based on TFD on different AOIs on product packages

In order to investigate whether there are differences in gaze allocation on different package elements in two study settings, we studied the total fixation duration (TFD), defined as the sum of all fixation durations in an area of interest

(AOI). The AOI 'text' was left out based on the consideration that the amount of text on different package designs varied greatly, and on small tea packages was limited to a few words.

We ran a general linear mixed effect model (GLMM) for repeated measures with Condition (Screen-viewing (2D), Physical display(3D)) as the between-subject variable and Package type (Cereal, Tea cylindrical, Tea rectangular) and AOI (Brand, Product name, Pictorial) as within-subject variables. Due to the positive skewness of the data, log10 transformation was applied to the data. Greenhouse-Geisser correction was applied in cases where the Mauchly's test of sphericity indicated a violation of the sphericity assumption. The findings revealed a statistically significant three-way interaction between Condition, Package, and AOI, $F(2.45, 132.47)=2.95$, $p=.045$. Statistical significance of a simple two-way interaction was accepted at a Bonferroni-adjusted alpha level of .025.

The simple two-way interaction between Condition and AOI was significant for Cereal packages, $F(1.30, 70.08)=6.13$, $p=.010$, as well as for Cylindrical tea packages, $F(1.25, 94.12)=5.38$, $p=.0081$ and on the border of significance for Rectangular tea packages, $F(2, 108)=3.61$, $p=.031$. To report the findings, inverse log function was applied to the transformed values. Pairwise comparisons with Bonferroni corrections revealed that on cereal packages the AOI Pictorial was viewed significantly longer in the 3D condition (M= 1572.86, 95% CI 1328.33 to 1862.41ms) compared to the 2D condition (M= 1018.79, 95% CI 885.51 to 1199.21ms), $F(1, 54)=13.75$, $p<.001$. Also on Cylindrical tea packages the AOI Pictorial was viewed longer in the 3D condition (M= 2554.27, 95% CI 2261.29 to 2885.2ms) than in the 2D condition (M= 1575.0, 95% CI 1400.33 to 1771.47ms), $F(1, 54)=32.79$, $p<.001$. The same applies also for Rectangular tea packages, where the TFD on AOI Pictorial in the 3D condition (M= 2902.72, 95% CI 2557.67 to 3294.32ms) was significantly longer than that in the 2D condition (M= 1948.54, 95% CI 1724.57 to 2201.61ms), $F(1, 54)=20.65$, $p<.001$. There were no significant differences in viewing time for AOIs Brand and Product name in the two viewing conditions. The back-transformed estimates for mean TFD values together with 95% confidence intervals are visualized in figure 8.

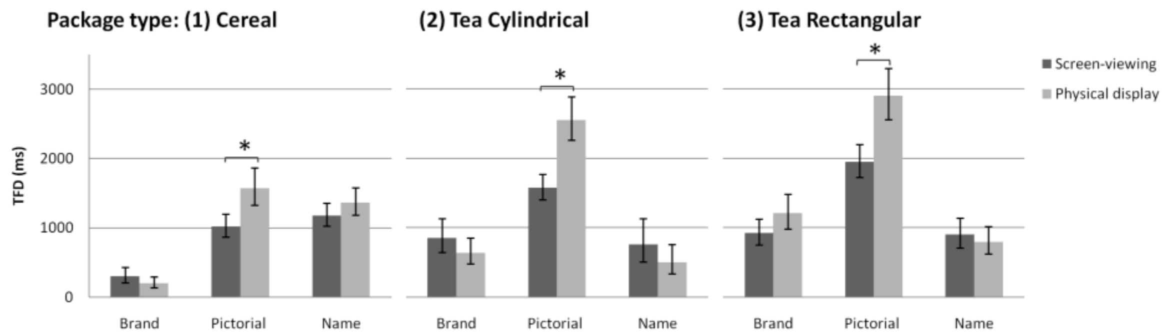

Figure 8: The estimated mean TFD values for different AOIs on different packages. The error bars signify 95% confidence intervals. Significant differences between the two viewing conditions are marked with an asterisk. As evident for all package types, viewers in the physical display condition tend to gaze the pictorial element longer than the viewers in the screen-viewing condition.

5.2.2 Analysis based on TFD on AOIs with different semantic content on product packages

There could be distinguished between two types of semantic information on product packages, pictorial and textual elements, with the latter comprising of brand name, product name and other supplementary textual or numeric information. The results from the previous analysis showed that participants in the physical display condition spent a significantly longer time gazing at the pictorial element on different packages, but does that also mean that in the screen-viewing condition the viewers focus more on the textual element? In order to investigate it further, we aggregated the TFD values on all textual elements (Brand, Product name and Text) in order to compare the allocation of attention to elements with different semantic content in the two conditions

Again, we ran GLMM for repeated measures with Condition (2D, 3D) as the between-subject variable and Package type (Cereal, Tea cylindrical, Tea rectangular) and AOI (Textual, Pictorial) as within-subject variables. Due to the positive skewness of the data, log10 transformation was applied to the data. The data revealed that the three-way interaction between Condition, Package type, and Semantic content was not statistically significant, $F(2, 108)=.846$, $p=.432$. However, there were statistically significant two-way interactions between Condition and Semantic element, $F(1, 54)=32.787$, $p<.001$, and between Package and Semantic element, $F(2, 108)=25.156$, $p<.001$.

To report the findings, inverse log function was applied to the transformed values. Pairwise comparisons with Bonferroni corrections revealed that on cereal packages the textual elements were viewed significantly longer in the 2D condition (M=3463.74, 95% CI 3098.47 to 3872.06ms) compared to the 3D condition (M= 2673.59, 95% CI 2381.97 to 3000.91ms), $F(1, 54)=10.46$, $p=.002$. Also on Cylindrical tea packages the Textual elements were viewed longer in the 2D condition (M= 2798.64, 95% CI 2367.61 to 3308.15ms) than in the 3D condition (M= 2072.01, 95% CI 1742.25 to 2464.18ms), $F(1, 54)=6.26$, $p=.015$. The difference in the viewing time for Textual elements on Rectangular tea packages was not significant, $F(1,54)=2.27$, $p=.122$. The back-transformed estimates for mean TFD values together with 95% confidence intervals are visualized in figure 9.

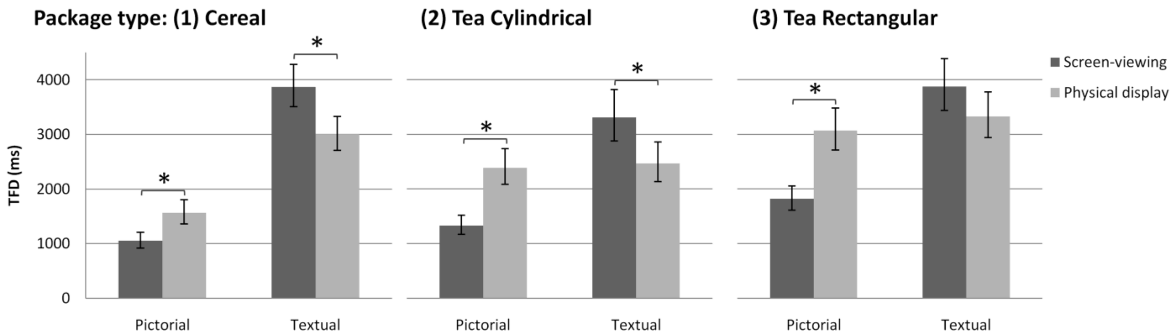

Figure 9: The estimated mean TFD values for AOIs with different semantic content. The error bars signify 95% confidence intervals and significant differences between the two viewing conditions are marked with an asterisk. For two package types the textual element is viewed significantly longer in the screen-viewing condition than in the physical display condition.

5.2.3 Analysis based on TTFF on different AOIs on product packages

Having found the differences in attention allocated to elements with different semantic content, it was decided to investigate whether there are also differences in the timing or order in which different package elements are fixated. As the dependent variable we considered the metric Time to Fist Fixation (TTFF), defined as the moment when the first fixation lands on an AOI.

Similarly to previous analyses, we ran GLMM for repeated measures with Condition (Screen-viewing (2D), Physical display (3D)) as the between-subject variable and Package type (Cereal, Tea cylindrical, Tea rectangular) and AOI

(Brand, Product name, Pictorial) as within-subject variables. Due to the positive skewness of the data, log10 transformation was applied to the data. The data revealed a statistically significant three-way interaction between condition, package, and AOI, $F(4, 184)=8.94$, $p<.001$. Statistical significance of a simple two-way interaction was accepted at a Bonferroni-adjusted alpha level of .025. The simple two-way interaction between Condition and AOI was significant for Cereal packages, $F(2, 98)=23.05$, $p<.001$, but not for Cylindrical tea packages, $F(2, 98)=.45$, $p=.638$, or Rectangular tea packages, $F(2, 108)=3.17$, $p=.046$.

To report the findings, inverse log function was applied to the transformed values. Pairwise comparisons with Bonferroni corrections revealed that on Cereal packages the AOI Product name was fixated significantly faster in the 2D condition (M=475.01, 95% CI 394.94 to 571.33ms) than in the 3D condition (M= 1427.64, 95% CI 1179.02 to 1728.68ms), $F(1, 54)=68.85$, $p<.001$. On Cylindrical tea packages the TTFF in the 2D condition was significantly lower for all AOIs: the AOI Brand in 2D condition (M=726.21, 95% CI 567.05 to 930.05ms) compared to the 3D condition (M=1315.40, 95% CI 1002.19 to 1726.49ms), $F(1, 51)=10.52$, $p=.002$; the AOI Product name in 2D condition (M=1375.34, 95% CI 1141.27 to 1657.42ms) compared to the 3D condition (M=2486.02, 95% CI 2033.48 to 3039.27ms), $F(1, 52)=18.77$, $p<.001$; and the AOI Pictorial in 2D condition (M=653.96, 95% CI 544.98 to 784.74ms) compared to the 3D condition (M=1469.53, 95% CI 1216.54 to 1775.14ms), $F(1, 54)=38.23$, $p<.001$. On Rectangular tea packages the AOI product name was fixated faster in the 2D condition (M=1242, 95% CI 1010.11 to 1528.81ms) compared to the 3D condition (M=1848.30, 95% CI 1491.1 to 2291.07ms), $F(1, 54)=7.113$, $p=.010$ and also the AOI Pictorial was fixated faster in the 2D condition (M=778.68, 95% CI 566.95 to 1069.48ms) than in the 3D condition (M=2036.75, 95% CI 1465.92 to 2829.87ms), $F(1, 54)=17.79$, $p<.001$. The back-transformed estimates for mean TTFF values together with 95% confidence intervals we are visualized in figure 10.

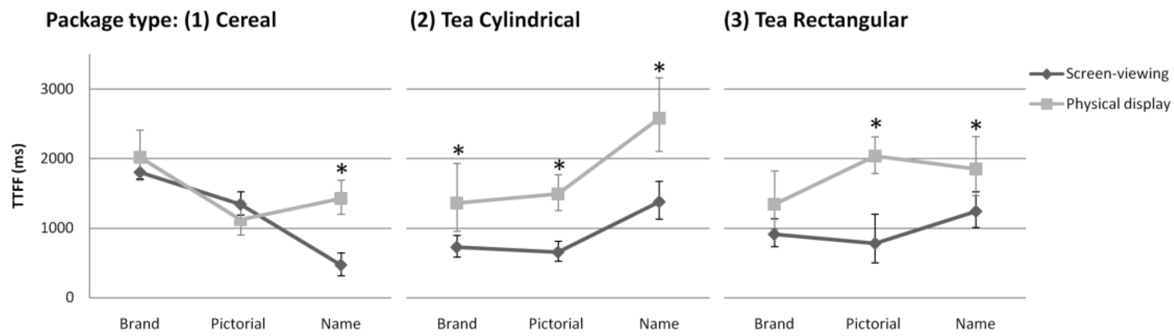

Figure 10: The estimated mean TTFF values for different AOIs on different package types. The error bars signify 95% confidence intervals and significant differences between the two viewing conditions are marked with an asterisk. In the majority of the the AOIs were fixated faster in the screen-viewing condition, implying a more rapid screening of the scene.

5.4 Discussion of findings

The focus of the second study was to investigate whether there are differences in how viewers attend screen-images versus three-dimensional scenes when stimulus dimensions and other variables related to the visual scene are kept constant. We investigated the characteristics of visual attention allocated to different package elements by focusing on two eye-tracking metrics, total fixation duration (TFD) and time to first fixation (TTFF).

The first analysis revealed that when viewing a package in its physical form, as opposed to a screen image, viewers gaze the pictorial illustration on the package longer. As the three types of packages differed significantly in their design and the presentation of the brand and textual information varied greatly across the items, it was decided to divide the AOIs into two groups based on their semantic content: pictorial versus textual. We aggregated the fixation durations on AOIs that contained any verbal or numerical information and compared the allocation of attention to the textual elements in the two viewing conditions. For two out of three package types, the textual elements were viewed significantly longer in the screen-based study setup than when exposed to the products in their physical form.

The comparison of TTFF values in the two conditions revealed that for all package types one or several package elements were fixated significantly faster when the stimuli were displayed on the screen. This implies that when exposed to a screen-image, the viewers tend to screen the scene at a faster pace than when looking at a physical package. Taken together, these findings suggest that even when all aspects related to the visual characteristics of the stimulus display are held constant, the stimulus display method has an important impact on the viewers' visual behavior. From that perspective, the findings call for caution when generalizing findings from screen-based eye-tracking studies to real-life settings.

6. Conclusion and further research

It was a decade ago when Benjamin Tatler concluded his article stating:

> "*It is vital that we rise to the challenge of moving studies of eye guidance firmly into natural settings in the next few years and evaluate whether our emerging models of eye guidance during scene viewing are anything more than descriptions of how we look at pictures*" (Tatler, 2009, p. 786).

Yet, while an increasing number of eye-tracking studies are conducted in naturalistic environments, very few studies have focused on evaluating whether the models of eye-guidance derived from screen-based settings can be generalized to the three-dimensional world. Considering the spread of the method in various academic disciplines as well as in practice, the relevance of the issue cannot be considered negligible. To exemplify, according to van der Lans and Wedel (2017), the number of eye-tracking articles published in marketing journals has risen from 1 article in 2000-2001 to 14 articles in 2014-2015. Also companies from various industries are increasingly using eye-tracking to design their marketing materials - the industry expects the eye-tracking market to be worth USD 1376.5 million by year the 2023 (MarketsandMarkets, 2017).

During the last decade a number of researchers have expressed the concern of whether controlled and highly artificial lab settings are adequate for findings on natural consumer behavior (e.g. Clement et al., 2013; Foulsham et al., 2011; Tonkin, Ouzts, et al., 2011). We ran two studies to investigate whether there are differences in how consumers allocate attention to stimuli presented on the screen versus in their physical form. To maximize the effect of the stimulus-based factors, we employed the free-viewing paradigm and investigated viewers unconstrained gaze guidance during the exposure to a product display and advertising banners (Study 1) and to various types of package designs (Study 2).

The findings of this study revealed some important differences in gaze patterns when exposing participants to two-dimensional screen images and to three-dimensional scenes. The first study revealed that when stimuli are compressed and presented on as screen-images, viewers allocate more attention to the lower part of the stimulus than in the physical display condition. It was also found that in the screen-viewing condition the viewers' fixation locations are more spread out across the stimulus area, whereas in physical display condition the fixations are more concentrated in the central part of the upper visual field of the display. In Study 1 the stimulus dimensions in the physical display condition were significantly larger, indicating that screening of the scene required movements of the head. Past research has suggested that viewing behavior in real world involves selecting fixation locations with head movements (Stahl, 1999), while eye movements tend to stay on a heading point slightly above the center of the head frame-of-reference (Foulsham et al., 2011). Thus, the differences in the gaze patterns could be attributed to different oculomotor processes.

The analysis of eye movements related to the viewing of packages in Study 2 shed light on some more fundamental differences between the viewing behavior in the two study settings. Even though the scale of the stimuli in the two viewing conditions was kept constant, we found differences in the duration of visual attention allocated to elements with different semantic content. Namely, viewers exposed to the packages in their physical form attended the pictorial element longer, whereas viewers in the screen-based setting focused more on the textual elements. For screen-based viewing, this finding may be associated with habit-related top-down influences. According to Henderson and Ferreira (2004), gaze guidance is dependent on short-and long-term episodic scene knowledge and scene schema knowledge and task knowledge, and accordingly, when seated in front of a computer screen and exposed to stimuli without an explicitly defined task, viewers may be more accustomed to acquire textual information.

Another explanation could be related to Gestalt perception, or how perceptual grouping and figure-ground organization are processed in relation to different stimulus presentations (Wagemans et al., 2012). A three-dimensional object with depth cues may be viewed and perceived more as a unified entity, whereas an image visualizing different elements of package design may trigger more attribute-focused attention. Also, studying landmark configuration and spatial encoding, Spetch and colleagues (1997; 1996) found that search patterns for humans differed between the search task in three-dimensional environments and in the analogous touch screen task, and Kelly and Spetch (2004) found that learning to use the geometry of a two-dimensional room schematic was more difficult than for three-dimensional models, leading the authors to elaborate that perhaps geometric properties represented by two-dimensional cues are less salient and more difficult to encode. Even though these findings come from completely different fields of research, they support the proposition that depth cues have an impact on how the viewer processes a stimulus.

Finally, a large body of literature has studied vision as a function of the processing via in dorsal and lateral pathways, typically referred to as ‘vision for action’ and ‘vision for perception’, respectively (Goodale & Milner, 1992; 2008). Whereas the role of the ventral stream is to provide information to enable the identification of a goal object, the dorsal stream relies on bottom-up information and uses visual information about the size, shape, and disposition of the object to program and control motor actions. Furthermore, the dorsal stream does not use the high-level perceptual representations and cannot be accessed consciously (Milner & Goodale, 2008). Milner and Goodale (2008) also argue that no task ever provides a pure measure of any given mental or neural process, indicating that there is no such thing as pure ‘visuomotor task’ or a pure ‘perceptual task’. This implies that exposure to a three-dimensional object is accompanied with non-conscious bottom-up processing of information in dorsal stream, preparing the viewer to carry out a movement (e.g. specifying the trajectory of the reach and the aperture needed for grasping the object). It is probable that a two-dimensional screen-image does not evoke such processing, or does so to a lesser degree. Differences in spatial encoding, in turn, may also affect the allocation and durations of fixation in different study settings, as our Study 2 found.

However, there is definitely a need for more studies investigating the influence of the study setting on consumers' visual attention and information processing. It should be acknowledged that the findings of the two studies are based on a small sample of participants and a small number of stimuli limited to FMCG category. Thus, it is not possible to rule out the effects of subjective preferences and brand attitudes, which may have affected the acquisition of visual information. By employing larger samples and a greater variety of stimuli, future research could bring more clarity to the impact of various drivers of gaze guidance in different study settings. Furthermore, visual attention is known to have downstream effects on memory formation, consideration, and choice. Thus, it would also be necessary to investigate how the study setting influences consumers' cognitive, affective and behavioral responses.

To conclude, the work presented in this research article suggests that consumers do not view marketing stimuli presented on the screen the same way as they view them in their physical form. This can be considered as a call for caution for researchers and practitioners who aim to generalize findings from screen-based settings to the viewing behavior in the three-dimensional world, and serves as an encouragement pay more attention to aspects such as physical realism and contextual cues in consumer research.

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4.2 Consumers in and out of context: Investigation of visual attention during choice process in different study setups

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Submitted to: Journal of Business Research, Special Issue on Eye Tracking Applications in Marketing

Abstract

How do findings established in the literature generalize to different approaches of studying consumer choice process? By employing eye-tracking methodology, the study investigates the role of the characteristics of a product display in guiding visual attention in three setups: computer screen, mock shelves and a real-life supermarket. The findings reveal that the relative impact of stimulus-driven versus goal-oriented factors in guiding attention is affected by the study setup and the confounding factors it entails. Across the three viewing conditions the data revealed differences in proportional viewing time allocated to different shelf levels and choice alternatives with a different number of facings. Also the center of the product display in screen-viewing condition attracted significantly more attention than in the supermarket. The study therefore warrants caution when generalizing findings from one experimental context to another and encourages researchers and practitioners to be more concerned about the aspect of external validity in consumer research.

Key words: eye-tracking; consumer behavior; decision making; product choice; external validity; retail

1. Introduction

The black box of consumer decision-making process has received a lot of attention and has been investigated by applying various paradigms and methodologies. Even though the majority of these studies are based on laboratory setups, articles on consumer behavior tend to assume, but rarely test the aspect of external validity. Publications often start out by reflecting on naturalistic conditions, for example, "*Picture yourself in a supermarket*" (Dijksterhuis, Smith, & Baaren, 2005, p. 193), or "*Consider the following scenario: You are at a local shopping center ...*" (Chartrand, Huber, Shiv, & Tanner, 2008, p. 189). This raises a crucial question: Do study participants exhibit the same behavior in laboratory experiments as they do in real life shopping environments?

This issue of generalizability also applies to eye-tracking studies where respondents are typically seated in front of a screen and given the task to choose the preferred item from a small set of alternatives. In such cases, the most traditional scenario would involve manipulation of some psychological or display-related factor, and the choice set would comprise of a few items with clearly distinct features. While investigations of visual attention in these artificial setups can lead to valuable insights related to information acquisition and preference formation, there is not much clarity with regards to whether the findings only apply to the decision-making process in the given setting or can be generalized to real life consumption situations.

It has been suggested that compared to highly controlled laboratory setups, the role played by deliberate conscious choice process diminishes significantly in naturalistic, noisy and complex environments (Bargh, 2002). Behavior and evaluations in naturalistic settings are to a large degree driven by automatic processes and affective responses that occur fast and often without any awareness (Bargh, 2002; Camerer, Loewenstein, & Prelec, 2005), and can be modulated by an enormous number of sensory variables, hedonic states, expectations, priming and social context (Dijksterhuis, Smith, Van Baaren, & Wigboldus, 2005; McClure et al., 2004). Furthermore, not only are consumers in retail settings exposed to a large number of marketing stimuli and choice alternatives, but atmospheric cues have also been shown to have a robust influence on shoppers' emotions, evaluations and behavior (Sherman, Mathur, & Smith, 1997; Turley & Milliman, 2000; Xiao & Nicholson, 2013).

Even though the aspect of external validity in consumer research has received considerable attention (Lynch Jr, 1982; Winer, 1999), only a limited number of studies have focused on the differential effects of the study setting. As an example, investigating the impact of the stimulus display method, Tonkin and colleagues (2011) found that compared to a screen-based display, large shopping displays facilitate faster search times. While models of visual attention during decision-making process have been developed for both screen-based stimuli (Krajbich, Lu, Camerer, & Rangel, 2012) as well as for multiple physical items (Russo & Leclerc, 1994), the impact of the study setup on visual attention during choice process, to the author's knowledge, has not been addressed.

Consumption-related decisions in retail contexts generally involve choosing the preferred item from an entire category of different product alternatives. When the study objective is to investigate consumer visual attention and/or choice behavior in relation to a certain category, an important consideration for both academic and commercial researchers becomes setting up the study with the optimal balance between internal and external validity. From the literature we find examples where the product display is presented as a static image (e.g Chandon, Hutchinson, Bradlow, & Young, 2009; Pieters & Warlop, 1999; Seva, Go, Garcia, & Grindulo, 2011), the participants interact with physical mock shelves (e.g Hurley, Hutcherson, Tonkin, Dailey, & Rice, 2015; Russo & Leclerc, 1994; Snyder, Hurley, Tonkin, Cooksey, & Rice, 2015; Tonkin, Ouzts, & Duchowski, 2011) or complete a shopping trip in a real-life supermarket (e.g. Clement, 2007; Clement, Aastrup, & Forsberg, 2015; Gidlöf, Wallin, Dewhurst, & Holmqvist, 2013). Without a doubt, these different setups vary in regard to the level of experimental realism, implying that also the cognitive and affective processes accompanying the choice process are likely to differ.

By applying eye-tracking methodology, the aim of this study is to compare the characteristics of consumer choice process in different study setups: in front of a computer screen, in a laboratory with a mock shelf and in a real-life supermarket. It is acknowledged that the different approaches employed entail various confounding factors that influence the decision-making process. Therefore, rather than attributing the differences in choice process solely to the stimulus context, the aim is to investigate the degree to which the findings established in the literature generalize to different approaches of studying consumer choice process. From a broader perspective, the study also investigates the role of the characteristics of the product display in guiding visual attention and contributes to the discussion on whether we can achieve generalizable results by studying consumers in controlled lab settings instead of noisy store environments.

The following section provides a brief review of literature on visual attention during decision-making process. Next, an empirical study comparing the characteristics of consumers' choice process in three different study setups is presented. The findings are discussed in relation to the existing literature and potential implications are outlined. Also suggestions for future research are proposed.

2. The link between visual attention and product choice

In natural behavior eye movements are tightly coordinated with subsequent actions with the purpose to accumulate sensory evidence that is relevant to these actions (Tatler, Hayhoe, Land, & Ballard, 2011). Information acquisition takes place during fixations, or short periods of time when the eye remains relatively stable, and the selection of gaze locations occurs via rapid eye movements called saccades (Duchowski, 2007; Holmqvist et al., 2011). Based on neuroscientific evidence, the selection of gaze locations is guided by two central factors: the gains in reward and uncertainty reduction (Gottlieb, Hayhoe, Hikosaka, & Rangel, 2014), but the literature on gaze guidance approaches the topic mainly by distinguishing between bottom-up and top-down attention (e.g. Foulsham & Underwood, 2008; Itti & Koch, 2000; Nyström & Holmqvist, 2008).

Even though the bottom-up and top-down attention, or stimulus- and goal-driven mechanisms in gaze guidance, respectively, represent overlapping organizational principles and interact to optimize attentional performance (Egeth & Yantis, 1997), numerous studies have debated their relative importance. In particular, computational models of saliency (Itti & Koch, 2000, 2001; Itti, Koch, & Niebur, 1998) have been applied in various study designs in order to assess their accuracy in predicting human viewing behavior. It has been shown that the saliency of product packages and packaging elements has an impact on their likelihood of capturing attention, which in turn has a positive impact on choice (Milosavljevic, Navalpakkam, Koch, & Rangel, 2012; Orquin, Scholderer, & Jeppesen, 2012). However, the effect of saliency has been argued to be smaller than that of top-down control, and factors such as semantic or contextual cues, object representations, and task instructions have been shown to override attentional capture by saliency (Kowler, 2011).

While saliency computations generally operate at a pixel level and fail to capture object representations, it has been argued that ‘proto-objects’, such as size, rough shape and location within a priority map, might pertain to a medium-level system between bottom up and top down gaze control (Wischnewski, Belardinelli, Schneider, & Steil, 2010). In line with that, the shape, the surface size and the location of products in a display have been shown to affect consumer attention capture and choice. The shape of a package together with its relative contrast have been shown to dominate the initial phase of consumer choice process (Clement, Kristensen, & Grønhaug, 2013). It has also been confirmed that the number of facings in a product display has a strong impact on visual attention (Gidlöf, Anikin, Lingonblad, & Wallin, 2017), which in turn increases the likelihood that the brand is included in the consideration set (Chandon et al., 2009).

With regards to the location within the priority map, it has been shown that products presented in the center of the screen receive more attention and are more likely to be chosen (Reutskaja, Nagel, Camerer, & Rangel, 2011). While in screen-viewing condition this phenomenon may to some degree be attributed to the central fixation bias, or the tendency to look more at the center of the screen (Tatler, 2007), the central position effect has also been shown to apply to physical products displays (Atalay, Bodur, & Rasolofoarison, 2012). However, Chandon and colleagues (2009) found that while top- and middle shelf positions gained more attention, top-shelf positions were more likely to lead to brand evaluation. This incongruence in the findings can likely be attributed to the differences in study designs and stimuli.

Aside from above-listed low-level features, there is also an array of cognitive or top-down factors that impact the allocation of attention and the course of the choice process. Ever since the studies by Buswell (1935) and Yarbus (1965) it has been known that the way humans move their eyes depends on task instructions, and alluding to the research on the phenomenon called 'change blindness', Hayhoe (2000) posits that visual system only represents the information that is necessary for the immediate visual task. Thus, in the context of product choice it would be expected that consumers attend preferentially to stimuli that are in alignment with their consumption-related goals. However, the question then becomes how do viewers know how to orient their gaze. Based on neuroscientific accounts, mechanisms controlling eye movements are closely linked to brain's reward system, and that sensitivity to reward modulates underlying neural mechanisms and facilitates extensive reinforcement learning (Hayhoe & Rothkopf, 2011). In other words, based on the feedback about the reward value of attending to particular stimuli, decision makers learn to distinguish between relevant and irrelevant stimuli through practice (Jovancevic-Misic & Hayhoe, 2009; Tatler et al., 2011). The learning effects are evident in repeated choice experiments, where viewers reduce the number of fixations over the course of repetitions and become more selective by allocating more fixations to important attributes such as price and brand (Orquin & Mueller Loose, 2013). These findings are in alignment with the reward-based theories on gaze guidance, but also point to the importance of decision-makers' subjective values and goals. These top-down factors that attract viewers' attention to important or high utility information, but are attributable to individual differences, referred to as '*utility effects*', have been shown to have a great impact on eye movements (Orquin & Mueller Loose, 2013).

There has also been a debate concerning whether the process of viewing itself has an impact on choice. A number of studies have demonstrated that during a choice process there is a gaze bias i.e. higher gaze frequency and/or longer gaze duration, toward the chosen alternative (Atalay et al., 2012; Bee, Prendinger, Nakasone, André, & Ishizuka, 2006; Glaholt & Reingold, 2009b, 2009a; Pieters & Warlop, 1999; Schotter, Berry, McKenzie, & Rayner, 2010; Schotter, Gerety, & Rayner, 2012). To exemplify, Pieters and Warlop (1999) found that when participants had to choose between six brands from four different categories, the chosen item received longer and more frequent fixations, and that this effect was present also when task motivation and time pressure were manipulated. This is supported by Janizewski, Kuo and Tavassoli (2012), who argue that attentional processes can prime down-stream cognitive processes, and prior selective attention to a product increases the likelihood of the product being chosen. Even though there are models of visual attention assuming that gaze plays a causal role in preference formation (Krajbich, Armel, & Rangel, 2010; Krajbich et al., 2012; Shimojo, Simion, Shimojo, & Scheier, 2003), the causal link between gaze and preference formation has been disconfirmed (Orquin & Mueller Loose, 2013). Studies have demonstrated that gaze allocation is not a necessary precursor for preference formation (Bird, Lauwereyns, & Crawford, 2012; Nittono & Wada, 2009) and that gaze bias is also present in decisions that are not preference-based (Glaholt & Reingold, 2009b).

While many studies on visual attention during decision making have used binary forced choice task (Krajbich et al., 2012; Milosavljevic et al., 2012; Schotter et al., 2010; Shimojo et al., 2003), it has been shown that an increase in the number of decision alternatives leads decision makers to become more selective in their encoding of decision information (Glaholt, Wu, & Reingold, 2010), reduce the duration of fixations, and acquire information from a proportionally smaller subset of items (Reutskaja et al., 2011). Indeed, in a naturalistic store environment consumers only attend a small subset, approximately a quarter

(Gidlöf et al., 2013) or a third (Clement et al., 2013) of all the options available on the shelf. Another factor that causes decision makers to reduce their fixation durations and be more selective in their information acquisition is time pressure (Pieters & Warlop, 1999; Reutskaja et al., 2011) which has also been shown to increase the downstream effects of visual saliency on choice (Milosavljevic et al., 2012).

To conclude, visual attention plays a crucial role in consumer decision-making and the literature suggests that there are numerous factors that may impact the allocation of visual attention and preference formation. Gidlöf and colleagues (2017) investigated the interplay between consumer preferences, product displays, visual attention and choices in a naturalistic shopping environment and confirmed that visual attention is by far the strongest predictor of product choice. Also products' popularity and compatibility with consumers' subjective preferences proved to be significant predictors of choice (Gidlöf et al., 2017). Based on a review of studies on eye movements in decision making, Orquin and Mueller Loose (2013) reach to the conclusion that final choice emerges as a result of complex interactions among stimuli, attention processes, working memory and preferences.

The empirical study presented in the following section compares consumer choice process in three different settings: in screen-viewing condition, in front of a mock shelf and in a real-life supermarket. As the three testing conditions differ significantly, the aim is to investigate the degree to which findings derived from studies focusing on consumer choice process apply to different study setups. For general comparison, the analysis first compares the decision time and the proportion of alternatives attended in the three conditions. Next, the three conditions are compared with regards to the presence of central fixation bias, gaze bias on the chosen alternative, the proportion of attention allocated to different shelf levels and the impact of the number of facings in guiding attention.

3. Study

3.1 Method

3.1.1 Participants

The data collection was carried out in three separate sessions, mobile eye-tracking studies in the store and in the lab condition, and a remote eye-tracking study based on the screen-viewing condition. A total of 87 participants were recruited in the capital area, involving both students from a business school as well as other volunteers. The participants were sequentially assigned to one of the three study groups, keeping the demographic composition across the groups as similar as possible.

In order to delimit the study of choice process to actual category users, one of the requirements for the participants was that they should consume breakfast cereals at least once a month. Based on the survey administered to the participants after the experiments, 21 category non-users were excluded from the sample. 4 participants were eliminated from the sample because they misunderstood task, leaving the total sample of 63 participants: 20 in the store condition, 19 in the mock-shelf condition and 24 in the screen-viewing condition (39 female, mean age 25.97, st.dev 4.54). The experiment lasted between 10 and 20 minutes, and participants were awarded a goodie bag or a selection of beverages for their participation.

3.1.2 Stimuli

In all three conditions the participants were exposed to the same display of morning cereal, consisting of three shelf units, with a total of 64 product facings and 25 different product variants. The product display together with areas of interest (AOIs) is visualized in Figure 1.

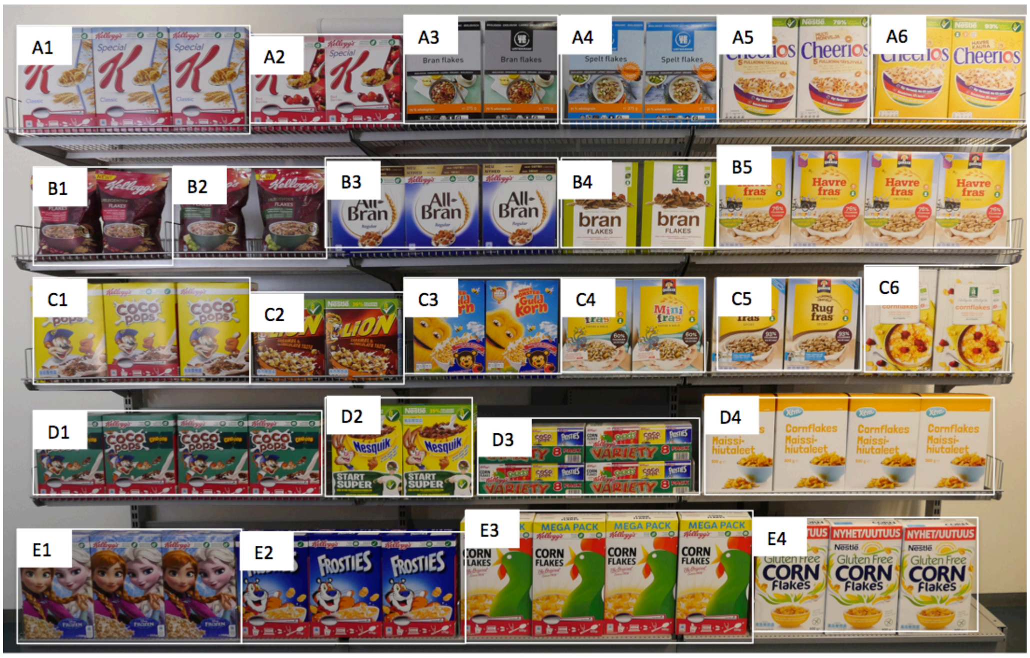


Figure 11: Product display with areas of interest (AOIs) corresponding to different choice alternatives

In the mock-shelf condition the participants only made a single choice and were only exposed to the critical stimulus. In screen-viewing and in supermarket condition the participants made in total 6 choices: breakfast cereal as the critical condition and coffee, tea, muesli, jam and crisp bread as fillers. In screen-viewing condition the participants were exposed to photographs of product displays taken in the same store where the experiment was conducted.

3.1.3 Procedure

In all viewing conditions the participants first signed the informed consent and were told that the aim of the study is to analyze visual attention during choice process, but were kept naïve about the product category. In all conditions the participants received task instructions in written form, telling them to choose the item that they would most likely purchase. No time constraints were introduced and the experimenters were not present during the choice process. After the experimental sessions the participants filled in a brief survey about their demographics and consumption habits and were briefed about the purpose of the study.

In screen-viewing condition the participants were seated in front of the eye-tracker and went through a 9-point calibration. To assure that the participants understand the task, the experiment started with two test rounds with images of household products, where participants had to click on the chosen item and note down the reason for their choice. After the test rounds the participants were informed that experiment the experiment was about to start, and were exposed to the sequence of 6 images of different product categories in randomized order.

Studies involving a physical product display started with equipping the participants with the eye tracking glasses and calibrating the gaze with calibration card individually for each participant. In the laboratory condition the respondents were walked into the experiment room and instructed to stand at 1.5m distance from the product display that was hidden behind a curtain. The lights in the room were then turned off, the curtain was removed, and the testing session started upon turning on the lights again. It lasted until the participant had made the choice and walked out from the experiment room with the chosen product.

In the store condition participants received a shopping list with six items listed in randomized order. The consideration behind such study design was to better resemble naturalistic shopping behavior, as consumers rarely walk into a store to buy only one item, and also to keep participants naïve about which part of the shopping process is of interest to the researchers. The participants were instructed to place all items in the basket but to walk out of the sales area without paying for the purchases.

3.1.4 Eye movement recordings and data pre-processing

Eye movements in mobile conditions were recorded using Tobii 2 Pro mobile eye tracking glasses with the sampling rate of 50 Hz /100 Hz and, screen camera of 1920 x 1080 with the resolution of 25 fps. In the screen-viewing condition the data was collected using Tobii T60XL eye tracker (1920 x 1080, 60Hz). The data was recorded and post-processed using iMotions Biometric Software version 7.1 and later data analysis was carried out using SPSS 24.0 statistical software.

Raw gaze samples were initially remapped from video frames to the reference image using iMotions automatic gaze mapping function. As the next step, the gaze remapping was manually checked frame by frame for all recordings and corrections were made where necessary. Fixation data was initially extracted using two default Tobii fixation detection algorithms with different velocity thresholds, Fixation Filter with 30°/sec and Attention Filter with 100°/sec threshold. According to Tobii documentation, the former is optimized for tasks such as reading, whereas the latter is more suited for dynamic conditions where respondents move around (Olsen, 2012; Tobii Technology, 2019). The fixation data based on both fixation detection algorithms were carefully compared to the scene recordings, revealing that the data output was not sufficiently detailed or accurate to describe viewing behavior across all three conditions (as the Fixation Filter based on default settings significantly reduced the data output, and the Attention Filter is some cases merged the gaze points across several AOIs into single fixations).

In order to more accurately capture the eye movements on the AOIs, the parameters of Tobii Fixation Filter (with 30°/sec velocity threshold) were modified so that no adjacent fixations were merged and no short fixations were discarded, leading to a significantly more detailed fixation data output for all three conditions, where all gaze samples with the angular velocity below 30°/sec were included. The durations of subsequent gaze points and fixations on individual Areas of Interest (AOIs) were aggregated to compute the total fixation duration (TFD) values per each visit. Visits with the TFD value below 100ms were excluded, similarly to Gidlof and colleagues (2017), who used 100ms as the cutoff point for dwells included in the data analysis.

It is acknowledged that several prior studies in dynamic environments have relied on manual coding of gaze points and the analysis of dwells (e.g. Clement, 2007; Gidlöf et al., 2017, 2013). However, an argument against that approach is that when the same data is analyzed based on dwell durations rather than the sum of fixation durations, the values are higher (by approximately 20%), as raw samples also include noise originating from the oculomotor system, the eye-tracker and the environment (Holmqvist et al., 2011). The approach adopted here is based on the consideration that the parameters for detecting fixations need to be suitable for comparing eye movement data from stationary and mobile viewing conditions. The modification of the fixation detection algorithm allowed to capture and include all gaze points with the angular velocity below 30 °/sec in the dataset (and include their duration when computing TFD values per each visit on the AOI). To assure accurate measures, the fixation data output was directly compared to the gaze recordings from all three conditions, revealing a very high level of accuracy.

To substantiate the data pre-processing approach, Miranda et al (2018), using the same mobile eye-tracking device, also applied the velocity threshold of 30°/sec when investigating eye movements during reading from paper and various digital devices, suggesting that similar criteria have been used also with other systems (e.g. Macedo, Crossland, & Rubin, 2011). Also former studies in mobile environments have relied on fixation data, but either have not discussed the parameters based on which the fixations were detected (e.g. Snyder et al., 2015; Tonkin, Ouzts, et al., 2011), or have used human coders to generate fixation data (Otterbring, Wästlund, & Gustafsson, 2016). In another study by Wästlund (2015), the analysis of visual attention was based on the number observations, defined as 'viewing an AOI without switching to another. This suggests that there are no standardized approaches when analyzing eye movements in the three-dimensional world. However, the velocity threshold of 30°/sec has been used as the parameter for the I-VT based algorithms in various settings, and the adjustments to the algorithm parameters (i.e. the inclusion of all gaze samples with the angular velocity below 30°/sec) further improved the detail and the accuracy of the data, allowing to compare the visual attention across all viewing conditions.

3.2 Results

To start out, the three study conditions were compared with regards to the decision time and the percentage of alternatives attended. The decision time in mobile conditions was defined as the period from the first gaze point allocated to the stimulus area until the moment the participant picked up the chosen item. In screen viewing condition the decision time was considered as the period from the stimulus onset until the participant clicked on the chosen item. The percentage of alternatives attended was computed for each participant as the number of AOIs that had a minimum of one visit (with the minimum TFD of 100ms) out of the total of 25 available alternatives.

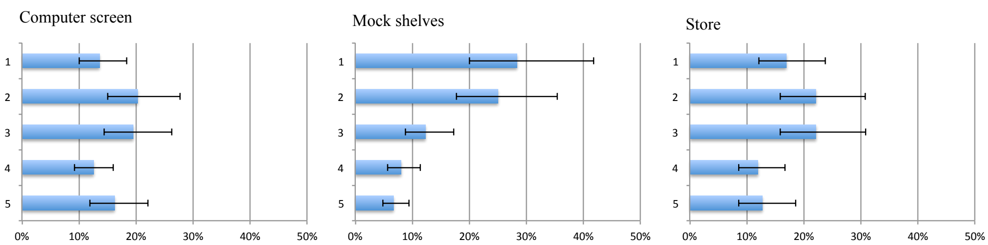
To describe the general patterns, it took the participants in average 13,95ms in screen viewing condition, 71,02ms in mock shelf condition and 22,97ms in store condition to choose the preferred item. In average participants attended 68.67% of the available alternatives in the screen viewing condition, 80.21% in the mock shelf condition and 53.6% in the store condition. The statistical analysis, in large part, had to rely on non-parametric tests due to the inherent characteristics of eye-tracking data, i.e. skewed distributions and presence of outliers. To estimate the differences in decision time, Kruskal-Wallis ranked sums test was used. The data revealed a significant difference between the three conditions, (χ^2= 17.30, p<.001), with a mean rank of 19.95 (mdn= 11.743ms) for screen viewing condition, a mean rank of 42.11 (mdn=62.092ms) for mock shelf condition, and a mean rank of 30.06 (mdn=20.902) for store condition. Steel-Dwass method was used for post-hoc pairwise comparisons. The findings revealed significant differences in mean ranks between the mock shelves and screen viewing conditions, Z=3.82, p<.001, and between the store and the mock shelves condition, Z=2.47, p=.036. The difference between the store condition and the screen viewing condition was not significant, Z=2.16, p=.077.

The same approach was applied for comparing the proportion of choice alternatives attended. Kruskal-Wallis ranked sums test revealed a significant difference between the three conditions, (χ^2= 13.59, p=.001), with a mean rank of 32.41 (mdn=68 %) for screen viewing condition, a mean rank of 42.82 (mdn=88%) for mock shelf condition, and a mean rank of 21.23 (mdn=52%) for store condition. Steel-Dwass method for post-hoc pairwise comparisons revealed significant differences in mean ranks between the mock shelves and store conditions, Z=3.27, p=.003, and on trend level between the store and the computer screen condition, Z=2.32, p=.052, as well as between the store condition and the screen viewing condition Z=.2.17, p=.076.

Proportional TFD time was computed for each AOI and for each participant by dividing the total TFD per AOI with the aggregated TFD time on all AOIs. To investigate whether the chosen item was fixated longer than other choice alternatives, nonparametric Wilcoxon rank sums tests were run comparing the proportional TFD on the chosen item versus the mean proportional TFD on other items that were attended but not chosen. The chosen item was fixated significantly longer in all viewing conditions (screen-viewing: χ^2= 32.5, p<.001; mock shelves: χ^2=20.88, p<.001; and store condition: χ^2=9.99, p=.002. However, there were no significant differences when comparing the proportional TDF on the chosen item across the three conditions (χ^2= 0.84, p= .655).

To check for central fixation bias, the proportional TFD on the AOI located at the center of the display (C3) was compared across the three conditions. Kruskal-Wallis ranked sums test revealed a significant difference between the three conditions, (χ^2= 8.04, p=.018), with a mean rank of 39.9 (mdn=4.38%) for screen viewing condition, a mean rank of 29.66 (mdn=1.78%) for mock shelf condition, and a mean rank of 24.7 (mdn=1.48%) for store condition. Steel-Dwass method for post-hoc pairwise comparisons revealed significant differences in mean ranks between the computer screen and the store conditions, Z=2.76, p=.016. The differences between the other conditions were not significant.

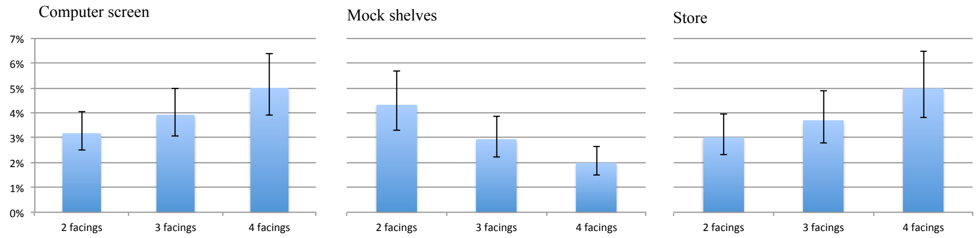
In order to test whether the shelf level has an impact on the allocation of attention, a linear mixed-effect model with REML estimation, random intercept and variance components structure was run. The response variable, proportion of fixation time allocated to each shelf level, was computed by aggregating the proportion of attention allocated to each AOI on each of the shelf levels per participant, and log10 transformation was applied to the data. The viewing condition, the shelf level and the interaction between the two were included as fixed effects and respondents as a random effect. The model revealed a significant interaction effect between the viewing condition and the shelf level (F (8, 287) =4.03, p<.001) and also the main effect of the shelf level was significant (F (4, 287) =11.28, p<.001). The main effect of the viewing condition was not significant (F (2, 287) =1.91, p=.151). To report the estimates the results were back-transformed. The estimates of attention allocated to each shelf level in each of the conditions, together with 95% confidence intervals, are presented in figure 2.



	Computer screen			Mock shelves			Store		
Shelf level	Estimate	Upper CI	Lower CI	Estimate	Upper CI	Lower CI	Estimate	Upper CI	Lower CI
1 (upper)	13.61%	10.07%	18.41%	28.32%	20.00%	41.78%	16.97%	12.08%	23.82%
2	20.28%	14.97%	27.80%	25.00%	17.66%	35.40%	22.09%	15.89%	30.76%
3	19.47%	14.39%	26.30%	12.30%	8.77%	17.26%	22.13%	15.89%	30.83%
4	12.59%	9.31%	16.00%	8.05%	5.68%	11.40%	11.92%	8.49%	16.75%
5 (lower)	16.23%	11.91%	22.08%	6.70%	4.78%	9.42%	12.74%	8.69%	18.66%

Figure 12: Estimates of attention allocated to different shelf levels (1 corresponding to the upper shelf and 5 corresponding to the bottom shelf). The bars signify the estimates for the proportion of fixation time and the whiskers signify 95% confidence intervals.

Also the impact of the number of facings on the proportional TFD was investigated by applying the linear mixed effect model with the same parameters as previously described. To compute the response variable, individual AOIs were grouped based on the number of facings. The mean proportional TFD was calculated on participant level and log 10 transformation was applied to the data. The viewing condition, facings and the interaction between the two were included as fixed effects and respondents as a random effect. The fixed effect test revealed a significant interaction effect between the viewing condition and the facings (F (4,177) =6.93, p<.001) and also the main effect of the viewing condition was significant (F (2, 177) =4.40, p=.014). The main effect of the number of facings was not significant (F (2, 177) =.18, p=.835). To report the estimates the results were back-transformed. The estimates of attention allocated to AOIs with different number of facings in each of the conditions, together with 95% confidence intervals are presented in figure 3.



	Computer screen			Mock shelves			Store		
Facings	Estimate	Lower CI	Upper CI	Estimate	Lower CI	Upper CI	Estimate	Lower CI	Upper CI
2 facings	3.18%	2.49%	4.06%	4.32%	3.28%	5.68%	3.01%	2.31%	3.94%
3 facings	3.92%	3.07%	5.00%	2.92%	2.22%	3.84%	3.69%	2.79%	4.89%
4 facings	4.99%	3.91%	6.37%	1.99%	1.50%	2.64%	4.98%	3.81%	6.50%

Figure 13: Estimates of attention allocated to AOIs with different number of facings. The bars signify the estimates of fixation time allocated to choice alternatives with different number of facings and the whiskers signify 95% confidence intervals.

4. Discussion of the findings

Allocation of visual attention plays an important role in consumer choice process, but to trace and analyze the visual behavior, researchers and practitioners face the challenge of deciding on the study setup and balancing between the aspects of internal and external validity. To minimize noise and the impact of various confounding variables, many studies are conducted in controlled lab environments, but do consumers behave the same when they are taken out from a naturalistic shopping context? To address this question, the study compared the allocation of visual attention during consumer choice process in three commonly used study setups: viewing stimuli as screen images, selecting among physical products in a simulated laboratory environment, and shopping in a real-life supermarket.

It is acknowledged that the three testing conditions differ not only with regards to the experimental realism, but also entail various confounding factors. In store and in screen-viewing condition the participants were instructed to make choices from different categories, thus being naïve about the critical stimulus. This was not the case for the mock shelf condition, as the participants were only exposed to a single product display. Furthermore, the price information likely had an impact on the decision-making process in the supermarket, but that information was not available in the screen-viewing and mock shelf conditions. In screen-viewing condition the participants were asked to make the decision based on a two-dimensional image presented on a computer screen, whereas in the store and in the mock shelf condition the participants were exposed to life-size physical product displays, enabling them to carefully investigate the information presented on the packages. Therefore, it is not argued that the study context was the only variable that differed among these three conditions. Instead, acknowledging the various confounding variables that are inherent to the study setups, the aim was to compare the characteristics of consumer visual behavior and investigate the degree to which findings established in the literature apply to consumer choice process in different study setups.

It was first tested whether there were differences in decision-making time, and the data revealed that the choice process was more than three times slower in the mock-shelves condition than in the other two conditions. The analysis of visual attention revealed that participants attended significantly more choice alternatives in the mock shelf-condition than in the supermarket condition. These findings may be attributed to the difference in the number of choices that the participants had to make, and the resulting perceived time pressure, which has been shown to cause decision makers to be more selective in their information acquisition (e.g. Pieters & Warlop, 1999; Reutskaja et al., 2011). The difference can also be due to other factors, such as the participants' reliance on price heuristics in the supermarket condition, or less accessible product information in the screen-viewing condition. However, as the choices in all conditions were hypothetical and as all participants reported to consume morning cereal at least on a monthly basis, thereby implying a basic familiarity with the category, the choice process should not necessarily require a deliberate investigation of price or product information. Therefore, the differences in decision time and the proportion of alternatives attended indicate that even if the stimulus characteristics are identical, various confounding factors can have a substantial impact on the level of deliberation and the resulting choice process.

Apart from the factors such as the number of choices and price information, another possible explanation for the differences observed between the store and the mock-shelves conditions can be that consumers in real-life shopping environments rely more on rapid automatic and affective responses, rather than cognitive deliberation, when choosing what to place in the basket, as suggested in the literature (e.g. Bargh, 2002; Bargh & Chartrand, 1999).

There were no differences between the three conditions with regards to the gaze bias towards the chosen alternative, but the proportion of attention allocated to the center of the product display differed significantly when comparing the screen-viewing and the supermarket conditions. Thus, the study confirmed the previous findings related to the central fixation bias in screen-viewing condition (Tatler, 2007) - a phenomenon which, through mere exposure effect, can contribute to the likelihood of the item being chosen, as found by Reutskaja and colleagues (2011). In the screen-viewing and mock-shelf conditions of this study the participants started the choice process facing the center of the product display, with the borders of the display clearly defined. This was not the case in the real-life shopping environment, where consumers were in dynamic interaction with product categories placed side by side. These findings indicate that the center of the product display in the store environment is likely to play a smaller role in guiding attention than in conditions where the boundaries of the categories are clearly visible. The presence of central fixation in screen-viewing condition, however, represents an important pitfall when generalizing findings from stationary setups to a dynamic store environment.

Perhaps the most interesting findings of this study are related to the allocation of attention to different shelf levels and display sizes, as measured by the number of facings, in different study setups. Due to various confounding factors and small sample sizes, of course, caution is warranted when making inferences based on the results, but nevertheless, the findings demonstrate clear patterns of how different study setups affect the effectiveness of low-level stimulus features in capturing visual attention. Based on a study in a real-life shopping environment, Gidlöf and colleagues (2017) found that products placed on middle shelves were more likely to capture visual attention than products placed on upper and lower shelves. In contrast, Chandon and colleagues (2009) exposed the participants to life-size images of product displays and found that while middle and top-shelf positions are gazed more than products placed on lower shelf levels, "*only top-shelf positions carry through to brand evaluation*" (Chandon et al., 2009 p.1). The study presented here also found that the upper shelves attracted the largest proportion of visual attention in the mock-shelves conditions, whereas in the store and screen-viewing conditions the allocation of attention was more evenly spread out, and concentrating slightly more on the middle and the second-highest shelf.

The impact of the number of facings on visual attention replicated the previous findings (e.g. Chandon et al., 2009; Gidlöf et al., 2017) in two out of the three viewing conditions. In screen-viewing and in store conditions a higher number of facings led to increased relative viewing time. In mock-shelves condition, in contrast, the results showed an opposite pattern. One explanation may be that in the store and in the screen-viewing condition the participant's viewing behavior was more influenced by the stimulus-related factors on the category level, whereas in the mock-shelves condition the participants focused more on product-level characteristics, such as claims of organic ingredients or fiber, focusing on choice options that had a smaller number of facings. Together these findings provide support for the argument that the interplay between stimulus-driven and goal-oriented factors in guiding visual attention is strongly affected by the study setup and the confounding factors it entails.

5. Conclusion and implications

A large part of the literature on consumer choice process relies on empirical studies conducted in controlled laboratory environments, but very few studies have addressed the aspect of external validity of these findings. Comparing consumer choice process in three different setups, the study found that the viewing behavior in a naturalistic shopping environment differed from that exhibited in the laboratory context. Apart from the differences in decision time and proportion of alternatives attended, which may be attributed to confounding variables related to the task and stimulus characteristics, the study found that the allocation of attention to the stimulus varied as a function of the study setup. In the store condition the center of the product display played a significantly smaller role in guiding attention than in the screen-viewing condition. Unlike in the mock-shelves condition where the upper shelves attracted the most attention, participants in the store focused more on the middle and the second highest shelf. It was also found that while in screen-viewing and store conditions a higher number of facings led to an increase in proportional viewing time, in mock-shelves condition the trend was the opposite. This implies that the factors guiding visual attention during consumer choice process are closely tied to the characteristics of the study setup.

Referring to findings based on static scene viewing paradigm, Tatler and colleagues (2011) suggested that as the dynamic and task-driven nature of vision is not represented in stationary setups, the models of gaze allocation are unlikely to generalize to a broader range of experimental contexts. The authors also suggested that in natural behavior eye movements are guided by principles such as behavioral relevance, uncertainty about the state of the environment and learned models of the environment (Tatler et al., 2011). This study extends the former proposition by revealing that in dynamic environments, even when the stimulus characteristics are kept the same, the choice behavior and the allocation of visual attention are greatly influenced by top-down factors that vary in response to the study context, specifics of the task and other variables that are inherent to the study setup. The context in which the study is conducted may have an impact on the degree to which the consumer perceives it necessary to rely on goal-oriented, rather than stimulus-driven attention, and that is manifest in different gaze patterns during the choice process in different study setups.

It is acknowledged that all viewing conditions investigated in this study involved artificial elements that reduced experimental realism - participants were involved in making hypothetical choices and knew that their viewing patterns were recorded. However, the findings suggest that when consumers are taken out of the naturalistic shopping context and the study setup is modified, also the choice process is different. As demonstrated here, it may not be feasible to set up a mock product display and expect that consumers' choice behavior in that setting will be identical to that exhibited in a store environment. Displaying stimuli on a computer screen, on the other hand, can introduce biases due to the dimensions of the scene as well as the viewers' tendency to gaze more at the center of the display. Caution is therefore warranted when generalizing findings from one experimental context to another.

To conclude, the study encourages researchers and practitioners to be more concerned with the aspect of external validity. Contextual overgeneralization in academic research may lead to distorted or misleading theories, whereas among practitioners it may result in erroneous decision making.

6. Delimitations and further research

The differences in the allocation of attention in response to specific stimulus characteristics indicate that the relative importance of bottom up and top down factors in gaze guidance depends on the characteristics of the study setup. However, as the participants in the simulated setting were not exposed to the prices of different choice alternatives and also the number of choices differed across conditions, it is not possible to attribute the differences in viewing behavior to the study environment. To better understand the degree to which the findings from controlled laboratory settings resemble those from noisy and complex real-life settings, more research based on directly comparable conditions is needed.

The study presented here only investigated consumers' choice process related to morning cereal category, but it is likely that the cognitive and affective processes underlying the choice behavior depend on the characteristics of the product category. Whereas morning cereal represents a low-risk low-involvement FMCG category where individual habits and preferences play an important role, the choice process related to more expensive or seldom bought items may differ markedly, and the differences in choice process elicited by the study setup may be smaller or non-existent. Thus, in order to better understand and assess the generalizability of the existing theories of consumer choice process, we need more studies that would investigate consumers' responses and behavior in relation to different categories and in different study setups.

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4.3 3D heatmap in marketing research and marketing practice – validation of an integrating model

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Submitted to: International Journal of Research in Marketing

Abstract:

The method of visualizing eye-tracking data as heatmaps or Gaussian-based attention-maps is intuitive and compelling and has been successfully utilized in stationary setups where respondents' viewing angle and distance are controlled for. Yet, with the introduction of wearable gaze trackers, eye-tracking data can be collected in almost any type of three-dimensional environment. Mapping and visualizing gaze data from 3D environments is not straightforward, and we argue that when viewers' distance and viewing angle are not accounted for, the parallax error and invalid Gaussian values distort the heatmap visualizations, decreasing their validity in capturing and communicating the allocation of visual attention. We demonstrate that the methodology of screen-based eye-tracking needs to be significantly adapted before it can be applied to three-dimensional settings. We present a method for mapping gaze points from a 3D environment onto a 3D heatmap and demonstrate its utility in experimental research design, thus providing an automated solution to researchers who run consumer studies in real life environments. Also marketing and managerial implications are discussed.

Keywords: Heatmap, eye-tracking, consumer research; retail marketing

1. Introduction

Rapid developments within eye-tracking technology over the last decade have contributed to its spread across a variety of disciplines. In the field of marketing it has been successfully utilized in studies on consumer decision making process both in screen-based (e.g. Pieters & Warlop, 1999; Reutskaja, Nagel, Camerer, & Rangel, 2011) as well as in real-life supermarket settings (e.g. Clement, 2007; Gidlöf, Anikin, Lingonblad, & Wallin, 2017). The present high-resolution eye-tracking technology also allows to investigate the drivers of voluntary and involuntary eye movements (Clement, Aastrup, & Forsberg, 2015; Hui, Fader, & Bradlow, 2009), and because visual attention leads to downstream effects on decision making (Gidlöf et al., 2017; e.g. Orquin & Mueller Loose, 2013), these aspects are important to consider when analyzing consumer in-store behavior.

During the last decade, the introduction of wearable eye-tracking glasses has contributed to studies moving away from artificial lab environments and towards uncontrolled real-life settings. The method enables to study consumers' responses to shelf-displays and in-store advertisements from the first-person perspective in naturalistic shopping environments, which in turn significantly increases the external validity of the findings (Clement, 2007). However, as the amount and complexity of data increase significantly, it also poses a great challenge for both academic and commercial research. Manually post-processing and analyzing the enormous amount of eye-tracking data from a sufficient sample size requires a large number of man-hours. For example, Pfeiffer and colleagues (2014) report that the manual coding of the eye movements of 20 respondents in four decision situations required about 80 hours. Thus, the analysis of mobile eye-tracking data can be highly resource demanding, and in order to avoid researchers and practitioners running the risk of drowning in data, automated approaches are needed.

Common for the analysis of both stationary and portable eye-tracking data is the focus on visual attention allocated to a certain area of interest (AOI), and Gaussian-based attentional heatmap is among the most common techniques for visualizing respondents' gaze behavior throughout a trial (Purucker, Landwehr, Sprott, & Herrmann, 2013). However, there are various challenges related to the analysis (e.g. Purucker et al., 2013), and visualization of eye-tracking data (e.g. Bojko, 2009), which poses a threat to the generalizability of the results. Nevertheless, as heatmap visualizations have the benefit of providing an intuitive illustration of where the respondents are more likely to direct their gaze, the method has a wide appeal in both marketing research and practice.

Attentional heatmaps can be built upon raw data samples or fixations and can be scaled with fixation durations. In order to minimize the possibility of misinterpretation, it is recommended to present the visualizations with accompanying quantitative analysis, as even small changes in the basic parameters for constructing heatmaps can significantly alter their appearance (Bojko, 2009). This pinpoints an important issue related to the analysis and visualization of eye-tracking data, namely, the lack of consensus and standardized approaches. Furthermore, the traditional method for visualizing gaze behavior assumes a two-dimensional stimulus display where the viewer's distance and viewing angle remain fixed. However, anyone who has ever visited a three-dimensional supermarket could affirm that consumers view in-store displays from different angles and distances. This raises concerns about the credibility of the approach and underlines the need for methods that can account for the characteristics of the study setting.

The lack of standardized approaches for proper analysis and visualization mobile eye-tracking data has potential consequences for both academia and commercial practitioners. In academic research the urge to obtain unambiguous and conclusive results often overrules the concern for ecological validity (Want, 2014) and the discussion of such limitations is simply moved to the final section of a paper together with calls for further research. In industrial settings these shortcomings can lead to erroneous decision-making with economic consequences. The objective of this paper is therefore to bring clarity to the discussion about the pitfalls and opportunities related to analyzing data from complex three-dimensional experimental settings. We provide a brief review of literature related to visual attention and consumer purchase process, describe the methodology for constructing heatmaps, and outline the problems related to applying the traditional 2D approach of constructing heatmaps to data collected from 3D environments. In order to address these issues, we propose a step-by-step model of constructing 3D heatmaps and validate it in an experimental research design (Jensen, Stets, Suurmets, Clement, & Aanæs, 2017 (an earlier version of the model was presented at SCIA conference 2017)).

2. Interpretation of visual attention

Eye movements play the central role in visual processing and are generally regarded as an overt behavioral manifestation of visual attention (Henderson & Ferreira, 2004). Visual attention is inferred from patterns of eye movements, where the acquisition of information takes place during fixations, i.e. short periods when the eye remains relatively stable. Humans' ability to obtain high resolution information from visual stimuli comes through the part of the eye called fovea, and attention selection involves bringing a stimulus into the focus of attention by foveating on it (Holmqvist et al., 2011; Pieters & Wedel, 2007). While there has long been a debate over how stimulus-driven versus goal-oriented attentional processes influence gaze patterns (e.g. Ballard & Hayhoe, 2009; Itti & Koch, 2001; Nyström & Holmqvist, 2008; Wolfe & Horowitz, 2004), according to neuroscientific accounts the encoding of visually salient features is based on novelty and reward (Gottlieb, Hayhoe, Hikosaka, & Rangel, 2014). This indicates that bottom-up and top-down attentional processes are closely intertwined, and assessing the influence of specific low- or high-level factors in attentional selection is highly complex.

While bottom-up factors are generally attributed to the visual characteristics of the scene, top-down processing is regarded as reflective of the interplay between higher cognitive factors such as viewer's task, goals, and familiarity with similar types of scenes (Nyström & Holmqvist, 2008; Sarter, Givens, & Bruno, 2001). In other words, any type of goal, task, or motivation during the viewing process represents an important cognitive factor impacting the allocation of visual attention to a scene. The classic studies by Buswell (1935) and Yarbus (1965) were first to demonstrate that fixation locations depend greatly on task instructions, and later accounts have argued that fixation control is essentially goal oriented, whereas the object of these goals translates into constellations of image features (Ballard & Hayhoe, 2009). Also in marketing context, specific processing goals related to advertisement viewing (Pieters & Wedel, 2007) or motivation and time pressure during brand choice (Pieters & Warlop, 1999) have been shown to have great influence on gaze patterns.

In regard to stimulus-related factors, it has been argued that attention selection is guided by the distribution of semantic richness of scene regions (Henderson & Hayes, 2017; Nyström & Holmqvist, 2008), and it has been shown that semantically informative objects trigger both higher number of fixations and longer sustained gaze (Henderson, Weeks Jr, & Hollingworth, 1999; E. F. Loftus, Miller, & Burns, 1978). Even though these indicators are commonly associated with intense cognitive processing, there is some ambiguity related to the interpretation of fixation durations. Namely, several studies on visual memory have focused on the number, rather than the duration of fixations (e.g. G. R. Loftus, 1972; Tatler, Gilchrist, & Land, 2005), as fixation durations can be influenced by the visual quality and the number of objects presented in the scene (Le Meur & Baccino, 2013). In other words, fixation durations not only reflect the depth and speed of processing, but can also be indicative of the participants' difficulty in extracting information or interpreting the stimulus (Dupont, Antrop, & Van Eetvelde, 2014). On one hand, it can be considered as an argument against scaling heatmaps with fixation durations, but from a wider perspective, such ambiguity related to the interpretation of eye-tracking metrics further contributes to the lack of consensus and standardized approaches in visual attention research.

3. Eye-tracking studies focusing on purchase decisions

While there have been different studies focusing on how consumers view marketing-related stimuli, only a fraction of them investigates the link between visual attention and product choice in a retail environment. One of the first studies that analyzed eye-movements in order to shed light on information acquisition during decision process was carried out by Russo and Leclerc (1994), where the authors proposed a three-phase model, consisting of orientation, evaluation and verification phases. However, instead of using eye-tracking equipment, the viewing behavior was videotaped through a one-way mirror. Compared to a real-life shopping environment, the laboratory setup differed in a number of ways, one of them being that the limited product display was made up of sparsely placed singular items.

A number of different studies have employed screen-based setups to investigate the impact of various factors on product choice. For example, Pieters and Warlop (1999) looked at how time pressure and task motivation influence visual attention during brand choice, Janizewski (1998) investigated the influence of layout on visual search and sales, and Huddleston and colleagues (2018) studied the relationship between display signage and consumers' likelihood to buy. Majority of theories and models linking visual attention and product choice are also generated based on screen-based setups. These include models on gaze cascade effect (Atalay, Bodur, & Rasolofoarison, 2012; Shimojo, Simion, Shimojo, & Scheier, 2003), attentional drift diffusion (Krajbich, Armel, & Rangel, 2010; Krajbich & Rangel, 2011) and decision process tracing (Glaholt & Reingold, 2011). While these studies have provided valuable insights in the mechanisms and variables involved in decision-making process, the generalizability of these findings into retail settings is questionable. Visual choice tasks with screen-based stimulus display not only involve unnatural tasks and contextual cues, but compared to retail environments, also much fewer choice alternatives.

In order to study visual attention allocated to product displays, studies by Chandon and colleagues employed a setup where participants were seated in front of a large (4x5 feet) screen. Their studies led to insights in relation to memory for brands (Chandon, Hutchinson, & Young, 2002), point-of-purchase marketing (Chandon, Hutchinson, Bradlow, & Young, 2006) and number and position of shelf facings (Chandon, Hutchinson, Bradlow, & Young, 2009). Also Seva and colleagues (2011) investigated the impact of number of facings, shelf position and packaging design on visual attention, but they used life-sized printed images as stimuli. Even though the stimulus dimensions in these setups resembled naturalistic conditions better, it can still be argued that these two-dimensional displays lack physical reality, and keeping the participants seated and explicitly reporting their choices may not be reflective of natural in-store choice behavior.

More importantly, the above-listed studies are based on a design where the viewing position and distance between the viewer and the stimulus are fixed, and therefore it remains unclear whether or to which degree the findings from static setups apply to naturalistic consumer choice process in real-life settings. In real life environments consumers can physically interact with choice alternatives, move around and screen the choice alternatives from various distances and angles. This implies that in order to investigate the patterns of consumers' viewing behavior and choice process in three-dimensional environments, the data analysis needs to account for spatial variations. For example, if a consumer is far away from the shelf display, then the information is acquired at low resolution and specific choice alternatives only make up a small fraction of the information attended. A fixation on the stimulus area made from far distance is therefore likely to carry less weight in terms of cognitive processing, compared to a situation where the participant is in close proximity to the stimulus object. Also, the underlying motivation driving the voluntary or involuntary eye movements is likely to differ depending on the spatial and temporal characteristics of the choice process.

In line with these considerations, Tatler (2009) encouraged researchers to move eye-tracking studies into dynamic environments in order to be able to evaluate '*whether our models of gaze guidance are anything more than descriptions of how we look at pictures*' (Tatler, 2009, p. 786). In the domain of marketing currently only a limited number of eye-tracking studies have been carried out in real-life shopping environments. Clement (2007) ran an in-store experiment, where the influence of package design was studied across five distinct phases of in-store buying decisions: pre-attention, succeeded attention, the tipping point, physical action phase, and post-purchase attention. A later study by Clement and colleagues (2013) investigated the relationship between package design features and consumers' in-store attention, and found that shape and contrast dominate the initial search phase.

Gidlöf and colleagues (2012) also carried out a study in a supermarket, revealing that central bias tendency (Tatler, 2007) is less robust in naturalistic settings, and that shelf position of products only has a minor effect on consumers' visual attention (Gidlöf et al., 2012). Investigating the differences between decision-making and search task in a supermarket, Gidlöf and colleagues (2013) found that dwell times are longer in the evaluation stage than in the orientation stage, which contradicts previous findings from lab studies. A later field study by Gidlöf and colleagues (2017) confirmed the findings that the number of facings and shelf position, visual saliency and personal preferences (but not familiarity) guide visual attention. The study also revealed that consumers are less attentive when they buy familiar product categories, and contrary to previous findings, they perform worse in familiar settings (Gidlöf et al., 2017).

With regards to these contradictory findings, it can be argued that in order to obtain ecologically valid results, studies on shopping behavior should be carried out in naturalistic retail settings. There is consensus in the literature that visual attention is one of the strongest factors influencing choice, but in-store experiments employing eye-tracking methodology have revealed that the proportion of products in a category that consumers attend to is only a bit higher than one third of all options in the category (Clement et al., 2013; Gidlöf et al., 2017). This indicates that nearly two-thirds of alternatives are not attended, which in turn eliminates the possibility that they would be considered for purchase (Orquin & Mueller Loose, 2013).

While the above-listed studies in dynamic environments relied on Areas-of-Interest (AOI) methodology, automatic 3D gaze mapping and corresponding heatmaps would not only provide intuitive illustrations of attention allocation, but could potentially also be used as the basis for quantitative analysis of gaze data. Before proposing the model for visualizing real-life gaze data from three-dimensional environments, the methodology and the basic constructs that define the quantitative basis and appearance of heatmaps need to be described.

4. The core constructs of attentional heatmaps

Attentional heatmaps provide a quick, intuitive, and compelling way to summarize and visualize the spatial distribution of eye movement data throughout the stimulus area. It is a diachronic method, meaning that the viewing behavior is modeled across the exposure time and the temporal dimension of viewing behavior is collapsed (Le Meur & Baccino, 2013). Attentional heatmaps are based on mathematical forms that allow to use them for quantitative testing (Holmqvist et al., 2011), but because even small changes in the basic parameters for constructing heatmaps can significantly alter their appearance, they can also be a subject for misinterpretation (Bojko, 2009). The method of visualizing eye-tracking data with Gaussian-based 'attentional landscapes' was first introduced by Pomplun and colleagues (1996) and later by Wooding (2002). While both authors used fixation data, they applied different Gaussian functions, and Wooding (2002) suggested to normalize the heatmaps using fixation durations. A closer look at how heatmaps are constructed points out some fundamental differences in approaches that need to be taken into consideration when designing 3D heatmaps.

Holmqvist and colleagues (2011) describe four parameters that determine how the Gaussian-based heatmaps look like: (1) the width of the basic construct (standard deviation), (2) whether raw data or fixations are used, (3) whether fixation duration is taken into account, and (4) the mapping from color to altitude.

The number of gaze points or fixations, fixation durations, and their spatial distribution represent the core constructs for most heatmaps. However, what constitutes a fixation can vary significantly depending on the characteristics of eye-tracking hardware and software. As described by Holmqvist and colleagues (2011) fixations in remote setups are most commonly detected with a clustering algorithm based on dispersion and duration information. In other words, in order to constitute a fixation, raw gaze samples have to be located within a spatially limited region (typically between 0.5 – 2.0°) for a minimum temporal duration (normally ranging between 50-200 ms) (Holmqvist et al., 2011). Thus, it is evident that both the dispersion and duration criteria typically vary by a factor of four. This exemplifies the issue related to the lack of standardized methods in eye movement research, indicating that the findings across different studies are not directly comparable.

While the software that is used with remote eye-tracking systems is typically based on dispersion-based event detection algorithms, mobile eye-tracking systems require a different approach, because in three-dimensional environments the distances between the viewers and the stimulus objects are in constant change. Most mobile eye-trackers, including Tobii 2 Pro glasses used in this study, employ a different algorithm, called Velocity-Threshold Identification (I-VT) fixation filter. This method assigns angular velocity to each gaze point given in visual degrees per second (°/s), and the gaze points with angular velocity below a certain threshold value are regarded as being part of a fixation (Salvucci & Goldberg, 2000). The criteria for defining and detecting fixations, again, can vary substantially.

The application of event detection algorithms also means that the oculomotor events that do not meet the criteria are eliminated from the fixation dataset – even if these short fixations or fixation blobs could reflect potentially important events (Holmqvist et al., 2011). Furthermore, Hooge and colleagues (2017) demonstrated that even though human classification of fixations is a common method for validating event detection algorithms, human coders apply different thresholds and selection rules, thereby arriving at different results. This further adds to the confusion as to what constitutes a fixation.

Due to the ambiguity related to the definition and detection of fixations, we argue for the use of raw data, rather than fixation data, when constructing heatmaps. Because raw data samples are not influenced by the event detection algorithm and its settings, they are closer to visualizing real eye movements (Holmqvist et al., 2011), and thus can be considered more reliable and more detailed. Yet, the main drawback is that in addition to meaningful eye movements raw data samples also include noise, such as saccades, drifts, tremors, and flicks. While Bojko (2009) recommends generating heatmaps from fixation data because raw data would intensify a heatmap and increase the likelihood for misinterpretation, Holmqvist and colleagues (2011) state that if the data is recorded with a high frequency and precision, heatmaps look more or less the same regardless of whether they are based on fixation data or raw data. Furthermore, the noise is likely to cancel out if the study is based on a sufficient number of participants, and increases in sample size also improve the validity and generalizability of the findings.

Therefore, from the perspectives of validity and reliability, we recommend that for constructing heatmaps it is more appropriate to use raw data and compromise the on the aspect of noise, rather than to use fixation data and incorporate the ambiguity that the event detection algorithms encompass.

5. Influence of viewers' spatial variations

As previously mentioned, the spatial distribution of fixations or raw gaze points forms the basis for constructing attentional heatmaps. The way how gaze points recorded in a mobile environment are generally mapped using commercial software is by finding the optimal correspondence between the reference image and the eye-tracker recorded video frame, and by simply mapping the gaze points according to a specific homography. However, it only works if the area of interest (AOI) is planar to the reference image and respondents are positioned at a right angle to the stimulus. If the stimulus area is not perfectly planar or the participant moves away from the corresponding position of the reference image, the gaze mapping will result in parallax error. Even when mapping a relatively flat area such as supermarket shelves, the parallax error can distort the results, for example by mapping the gaze location next to a price tag rather than on it. Figure 1 visualizes the inherent differences between mapping gaze points when the 3D structure is taken into account (upper row), versus based on simple homography (bottom row.)

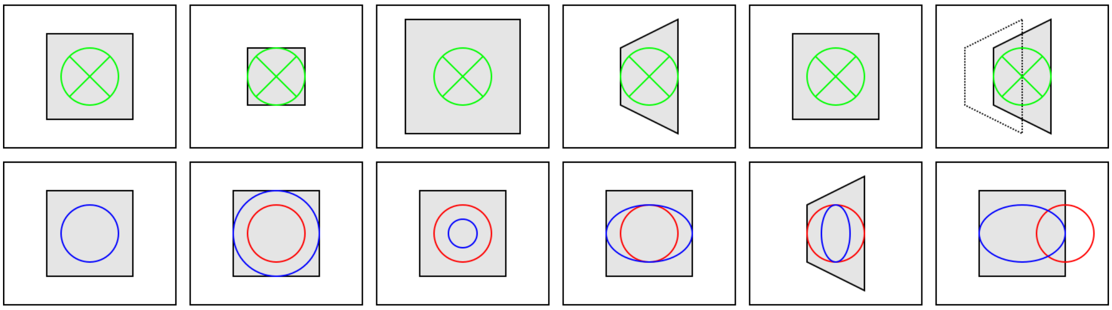

Figure 14: The top row shows the point of view with the gaze point in green and the AOI as a grey square. The second row shows the attention mapping to a reference with red being the 2D mapping based on homography, while the blue shows a 3D AOI mapping.

Furthermore, the composition of the viewed scene has a significant impact on how the 3D heat map will differ from the traditional homographic mapping method. To visualize the effect of a 3D mapping versus the traditional homographic method, we simulate both scenarios to allow for a visual comparison. Figure 2 shows examples of different shapes that occur in real-life settings, and how the mapping of a single gaze point differs.

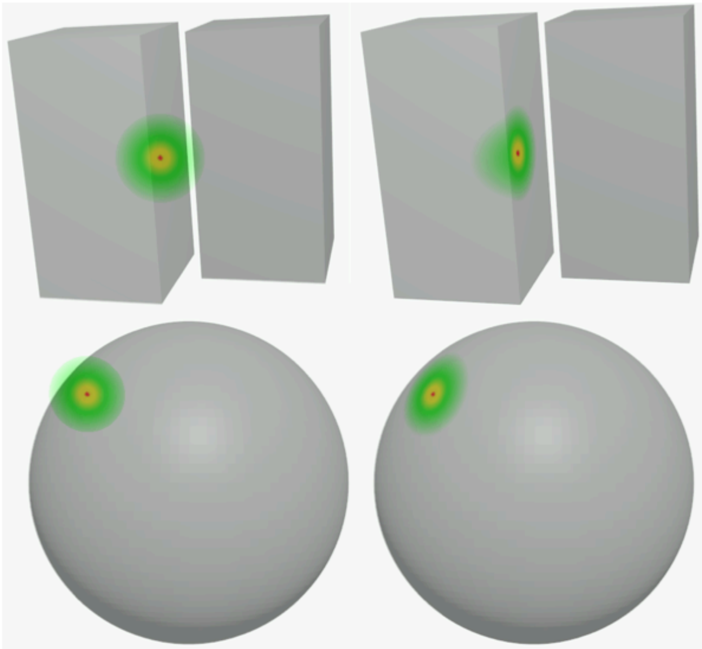

Figure 2: Exemplification of the difference between traditional homographic mapping (left) and 3D gaze mapping (right) using simulations. A single gaze point is visualized on different shapes.

The homographic method we compare against does not contain information about the scene geometry and displacement between the respondent and the gaze mapping reference image. Consequently, the difference between a homographic mapping and the 3D mapping is investigated by considering the angle and the spatial distance between the respondent and the observer, respectively, as illustrated in Figure 3.

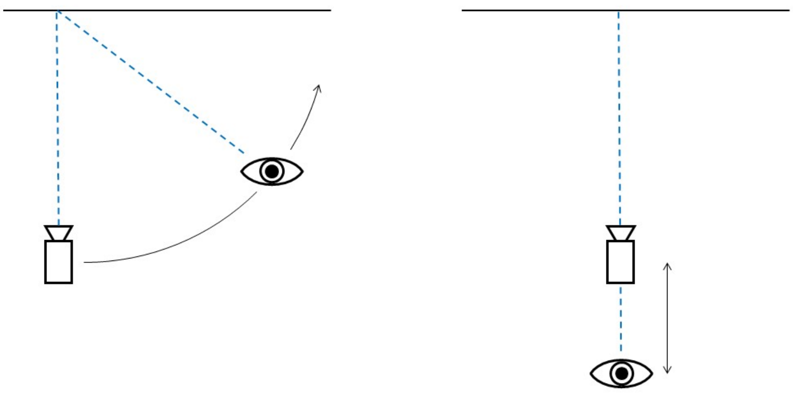

Figure 3: (a) Altering the angle between the observer (the camera capturing the image used for the 2D heat map) and the respondent (the eye position and gaze direction). (b) Altering the distance between the observer and the respondent.

We compare the shape of the foveated area, F, on a flat surface, and observe the difference between a 3D mapping and the traditional homographic mapping using the Intersection over Union (IoU),

$$IoU = \frac{F_{Homographic} \cap F_{3D}}{F_{Homographic} \cup F_{3D}} = \frac{Area\ of\ Overlap}{Area\ of\ Union}$$

Where $F_{Homographic}$ is the foveated area mapped onto a flat surface using a traditional homographic mapping, and F_{3D} is the foveated area mapped onto a flat surface using the 3D mapping. A perfect overlap (IoU = 1) is when the observing camera and the respondent are in the same position, and the overlap decreases as the distance or angle between the two increases. The result of the two scenarios from Figure 3 is shown in Figure 4.

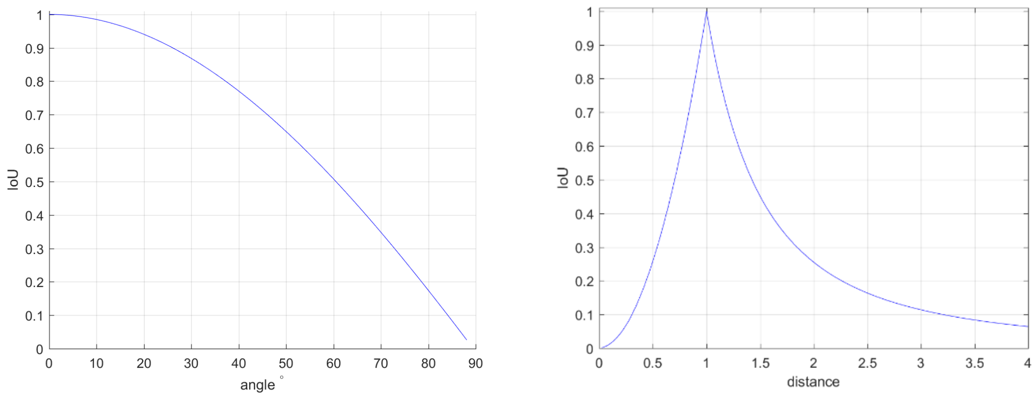

Figure 4: Plots showing the similarity of the 3D vs. the homographic mapping of the foveated area as the viewing angle (a) and distance between the observing camera and the respondent (b) changes. Note that the distance is kept constant when the angle between the observer and respondent is increased. At distance 1, the observer and respondent are at equal distance.

As evident from figure 4 (a), when the deviation in the viewing angle between the respondent and the observing camera is below 20 degrees, then the intersection over union remains above 95%. However, as the deviation in viewing angles reaches above 60 degrees, the intersection over union falls below 50%. Figure 4 (b) visualizes how changes in distances have even more drastic effects on the accuracy of mapping the foveated area. To exemplify, when heatmaps are constructed based on gaze points from a remote setting, it is assumed, for example, that the respondent's distance is fixed at approximately 60 cm from the screen, and the foveated area corresponds to approximately one to two degrees of visual field (Holmqvist et al., 2011). These parameters will allow to construct a heatmap where the Gaussian values accurately reflect the foveated areas. In contrast, when the data is collected in a mobile environment, there is perfect correspondence between the homographic gaze mapping and the actual foveated area only as long as the respondent stays at 60cm distance from the stimulus. If the respondent's distance changes by 50% (e.g. to 30 cm or 90 cm from the stimulus), the intersection over union value drops below 50%.

These simulations clearly demonstrate that even small changes in viewers' distance and viewing angle have significant impact on the shape and size of the foveated area. Therefore, we argue that gaze data collected from a three-dimensional environment and mapped homographically onto a reference image will almost always suffer from perspective and parallax error, resulting in incorrect mapping.

5. Method: Building a model for 3D gaze mapping

Based on the argumentation presented in the previous section, we propose a model, where gaze data from real-life environment recordings are mapped onto a 3D-modelled AOI representing the environment being investigated. To achieve this, we propose a 3-step approach: (1) construction of a 3D AOI, (2) positioning each frame from the eye-tracker relative to this AOI, and (3) finally creating a 3D heatmap by mapping the gaze points onto the 3D modelled AOI representation. The pipeline is shown in Figure 5.

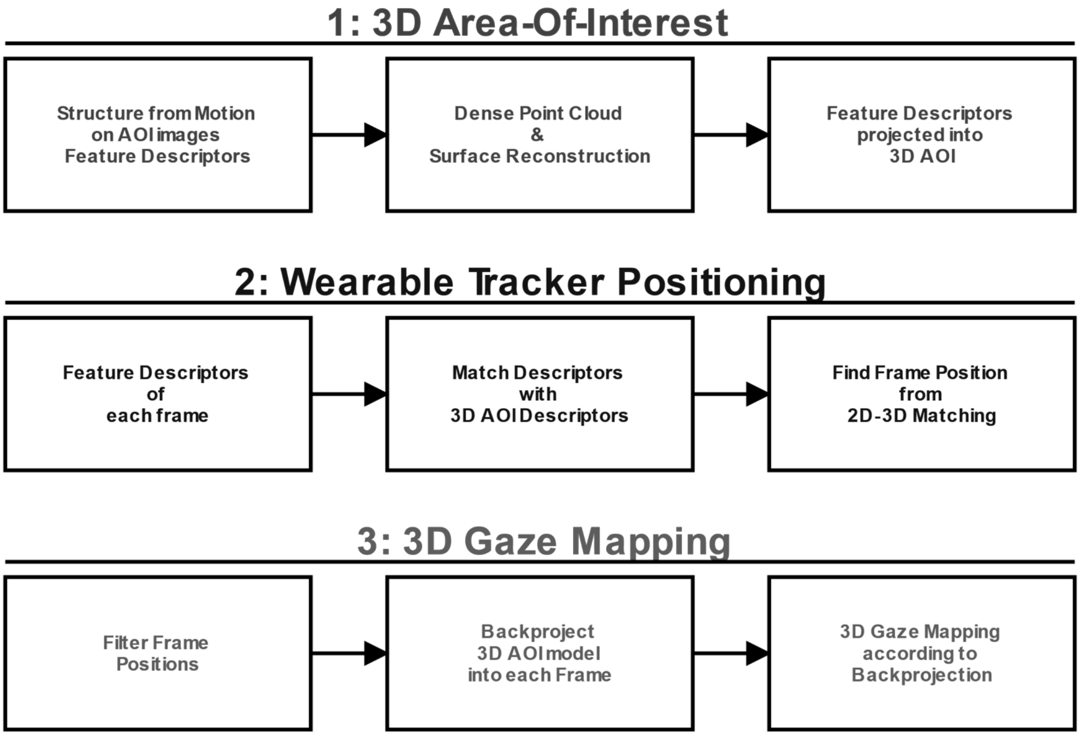

Figure 5: Schematic view of a model for 3D heatmap with three parts with each three steps.

5.1 Creating a 3D representation of the AOI

The first step is to construct the 3D AOI representation, which again consists of three steps. The 3D AOI representation is built from a series of reference images taken with a regular camera. We use Structure-from-Motion – SfM (Koenderink & Van Doorn, 1991) in order to find the spatial camera positions, which requires a sequence of images followed by an image rectification based on the parameters obtained from a camera calibration. Unique image features and descriptors were found for each image using SIFT (Lowe, 2004; Vedaldi & Fulkerson, 2010), and then matched sequence by sequence for all images in an iterative fashion. Images with sufficient matching features were included, while extrinsic parameters were refined by using bundle adjustment (Triggs, McLauchlan, Hartley, & Fitzgibbon, 1999). Given the estimated camera positions a dense cloud of the AOI is constructed using the multi-view stereopsis algorithm proposed by Furukawa and Ponce (2007). This method robustly produces a dense representation from which a surface is reconstructed using Poisson surface reconstruction (Kazhdan, Bolitho, & Hoppe, 2006). Figure 6(a) shows an example a 3D AOI of a supermarket cereal section.

Figure 6: The visualization on the left shows the 3D AOI and the visualization on the right shows a back projection of the AOI into a frame from the tracker (the projection is in color, while the frame is in black and white).

In order to localize the wearable eye-tracker later in the pipeline, we made use of back projection and depth management of the 3D AOI for each reference image. This procedure made it possible to project 2D SIFT image descriptors into 3D space, and by that matching the 2D descriptors between each frame from the wearable eye-tracker and the 3D AOI.

5.2 Positioning the wearable tracker

In the second part, each frame from the wearable eye-tracker has to be positioned relative to the 3D AOI map in order to correctly map gaze data. Image descriptors in each frame (SIFT) are matched with the descriptors from the 3D AOI. Using these correspondences, 2D-3D pose solver finds a camera pose using a RANSAC approach discarding outliers using OpenCV. Given enough sufficient corresponding points, the solver will return a correct camera pose in relation to the AOI map. This can be seen in Figure 6(b) showing the 3D AOI back-projected into a given frame using the estimated camera pose. However, a situation might arise where a frame might not cover any part of the AOI, and then the camera pose might not be valid. In either case, the back projection will then provide us with a validation check, showing the correctness of the pose estimation, because the back projection should seamlessly match the frame and incorrect pose estimations tend to be very inconsistent from one frame to the next.

5.3 Mapping the gaze points and constructing the 3D heatmap

In the last and third part the 3D gaze points are finally mapped. As the pose estimation process is unfiltered, some minor filtering will help to remove incorrect poses. Correct pose estimates between frames vary very little, while incorrect poses show a far more erratic behavior from one frame to the next. This makes it easy to filter poses based on spatial inconsistency. Figure 4 shows the positioning with filtering, which removes spatial inconsistency between frames. Looking at numbers of inliers returned from the 2D to 3D pose solver gives us a good indication of the correctness, yet thresholding this number does at the same time also remove some correctly found poses.

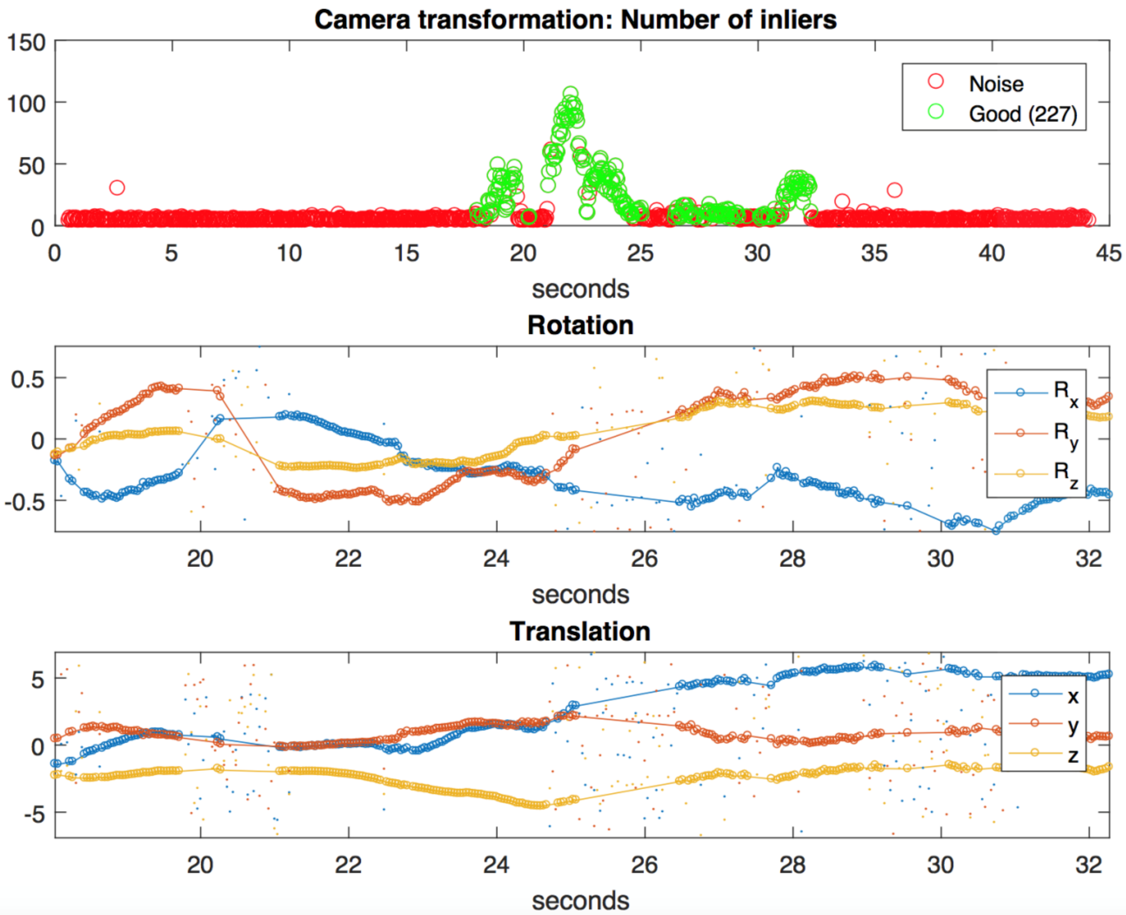

Figure 7: From top to bottom: the framewise number of inliers in the camera positioning solver, where greens are considered reliable and reds are noise. Secondly and thirdly, the rotation and translation with inliers are shown as a connected graph and outliers as single points.

With the pose estimated and filtered, we should be left with pose data for every valid position, where the respondent looks at the AOI. Figure 8 shows the movement of a respondent in front of the AOI. For each frame with a valid pose we can map the gaze point onto the surface model. Rather than finding the gaze line of sight intersect with the 3D map, the point is now found using back projection into the current frame.

Figure 8: One respondents' movements in front of the cereal category (colored shapes) represented on the AOI backprojection.

When creating the 3D heatmap, a small Gaussian area around each gaze point is added to the backprojection of the 3D AOI, which is finally added as a sum of Gaussians in 3D space. This 3D sum of Gaussians ultimately creates the 3D heatmap (Figure 9).

Figure 9: The 3D heatmap created on the 3D AOI as a backprojection

In line with the arguments related to the ambiguity of defining fixations in real-life environments, we construct the heatmap from raw data. As the gaze is mapped onto three-dimensional AOI model, we also avoid the perspective and parallax error that accompany the gaze mapping based on 2D homography (presented in Figures 1, 2 and 4). Since we add the Gaussian contribution in the back projection of the AOI, this contribution stays constant relative to the area covered. It means that if a person is close to the shelf then the shown gaze point will be small and with high intensity. For a person standing away from the shelf the shown gaze point will cover a larger area, yet it will be less intense and more spread out. This is in correspondence with viewers' visual acuity that is dependent on their distance from the stimulus objects. When viewers are looking at the shelf from an angle, the shape of the contribution will in the same way change to an elliptical form, thereby avoiding the parallax error. Since the sum of all calculated gaze points is done in 3D, the heatmap can be projected into any frame with a calculated pose, and any reference image can be used to create the 3D AOI map.

6. Testing the 3D gaze mapping model with empirical data

6.1 Method

The data was collected from both a real-world supermarket as well as from a mock-up supermarket shelf in our lab. The product display with regards to the number and placement of choice alternatives was identical in both settings, consisting of 25 different variants of breakfast cereals. Even though the differences between 2D and 3D heatmaps would be more drastic for end-of-aisle and stand-alone displays, which can be viewed and approached from various directions, we chose to use a planar stimulus area.

A total of 12 respondents (8 female, mean age 28.58, st.dev 5.63) were recruited from the capital region. They were randomly assigned to carry out the forced choice task either in the store or laboratory setting (6 respondents in both conditions) while their gaze patterns were recorded. It is acknowledged that the empirical study is based on a rather small sample of viewers, however, as the aim of the study is to compare two methods of data visualization, we did not regard it as a problem. Studies focusing on the methodological side of visualizing of eye-tracking data have used the gaze points of 3 (Le Meur & Baccino, 2013) and 13 (Bojko, 2009) viewers per heatmap.

Data for the reference AOIs were collected using a simple digital mirrorless *Panasonic GH4* camera with a 12mm lens, while data from test persons were recorded using wearable eye tracker *Tobii Pro Glasses 2* with the sampling rate of 50 Hz /100 Hz and, screen camera of 1920 x 1080 with the resolution of 25 fps. Both cameras were calibrated using a standard checkerboard approach (Zhang, 1999). Photos from the digital camera were used to make sufficient sets of reference images to cover all the desired AOIs, resulting in 12-20 images of each AOI. The gaze data were in the form of raw data samples, so no fixation filtering was applied (Holmqvist et al., 2011). Eye-tracking data was recorded using iMotions biometric software 6.3 and the same software was used for homographic gaze mapping and construction of 2D heatmap.

6.2 The process of building the 3D Heatmap

The proposed three-step approach is fully automatic and runs at <1 frame per second using a mix of Matlab, mex, vlfeat and OpenCV. A full C++ implementation could have been utilized to speed up the process, but we aimed to demonstrate a feasible pipeline, making it possible for researchers to optimize their time on the processed results. The core of the pipeline is the ability to correctly estimate the position of the portable eye-tracker relative to the 3D AOI in each frame. The filtering process in the last part of the pipeline assigns each frame in one out of four categories: true negative (correctly not detecting AOI), true positive (correctly detecting AOI), false positive (incorrect detection of AOI), and false negative (incorrectly not detecting AOI).

Reviewing output videos with 3D AOI overlay back projected as presented in Figure 3(b) is an easy way to quickly assess the quality of the AOI detection. Such qualitative reviews show very few, if any false positives but some false negatives in frames with motion blur, oblige viewpoint angles and occlusion.

Since *Tobii Pro Glasses 2* have a very small sensor, challenged by low in-store light quality, it results in frames with motion blur from head movement as well as rolling shutter. These in-store settings are a major cause of false negatives, yet looking from a distance, other shoppers standing in the way and other in-store elements blocking the sight line can also cause false negatives. Reviewing the frame positions as a graph shown in Figure 7 and at the same time looking at the spatial position shown in Figure 8, it makes it possible for us to do quick qualitative verifications.

6.3 The results

As previously stated, heatmaps provide a quick and intuitive way to visualize the spatial distribution of eye tracking data, but can also be misleading or misinterpreted. We have brought up the issues related to the perspective and parallax error that result from mapping real-life gaze data based on 2D homography, as well as the ambiguity of defining fixations. We have thus recommended to construct 3D AOI models on which to map the gaze data and construct such heatmaps from raw data samples.

In order to assess whether this method results in a heatmap that is quantitatively and qualitatively different, we have back-projected the 3D heatmap to a reference image. The same image has also been used for homography gaze-mapping using iMotions 6.2 software. The two heatmaps are shown in Figure 10.

Figure 10: Heatmaps based on 3D gaze-mapping (left) and 2D gaze-mapping (right). For the 3D mapping the heatmap has been backprojected into one of the reference frames used for the 2D mapping

While both of these heatmaps presented in figure 10 are based on raw data samples, the gaze data visualized in 2D homography based heatmap (right) does not account for the distances nor the angles at which the viewers gaze at the visual scene. Not only is the gaze data visualization distorted due to parallax error, but all gaze points, regardless of the viewers' distance, have the same Gaussian value. As visible on the comparison of the two visualizations, the 2D heatmap results in more intense *hotspots* and lower variability in gaze distribution. The 3D heatmap, which we argue to be a more valid visualization of the real-life allocation of visual attention, depicts the same *hotspots* with a more spread out distribution of the gaze data.

Based on these results we argue that applying the methods designed for 2D eye-tracking data to analyze 3D data samples introduces significant biases in the results. When viewers' distance and viewing angle are not accounted for, the parallax error and invalid Gaussian values distort the heatmap so that it fails to capture and communicate the actual allocation of the visual attention.

7. Marketing implications

The main aim of this article is to contribute to the discourse and methodology related to conducting studies in naturalistic settings and help researchers and practitioners to move their eye-tracking studies from laboratory to real-life environments. By automizing the gaze mapping process and accounting for spatial variations in viewers' location, the model not only provides a solution that makes the data analysis faster and more efficient but also contributes to the ecological validity of the results.

When constructed and interpreted correctly, heatmap visualizations provide a clear and unambiguous visualization of consumer visual attention. In academic research the method can contribute to the theoretical basis for understanding and measuring attention, and also support preliminary studies. In marketing context the method provides the possibility for testing visual features of packaging designs, size and location of product displays and other factors that are relevant for in-store marketing. Among practitioners attentional heatmaps are widely used as a tool supporting managerial decision making, and therefore it is important that the visualizations communicate the information in valid and reliable manner.

The model presented in this article can be considered a framework for further development for analyzing data from portable eye-trackers. For example, the review of literature pointed out several studies that distinguished between different decision-making phases in consumer choice process. Eye movements that accompany the cognitive processes during the orientation, evaluation and verification phase differ (Clement et al., 2013) and do not carry equal weight in terms of their contribution to formulating a preference-based choice. The proposed method allows to construct separate heatmaps for different decision phases, and thereby shed light on the temporal and spatial dimensions of consumer visual attention during choice process.

Research in the field of neuromarketing (Sutherland, 2007) has to a large extent relied on laboratory-based experiments where real-life situations are simulated in artificial, and often screen-based settings. The reluctance to leave the lab and conduct studies in real-life environments might stem from the lack of equipment, but also from higher demands for software that would enable to analyze large amounts of complex data in an efficient manner. Concern for obtaining valid results together with skepticism towards the methods or software available for biometric research may further hinder the transition. The empirical study that formed the basis for testing the method of 3D heatmaps is not itself a pioneering approach in consumer research but allowed us to present a method that supports conducting studies in environments where actual consumption takes place.

8. References

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5. CONCLUSION AND GENERAL DISCUSSION

5. Conclusion and general discussion

The dissertation starts out with outlining three issues that limit the credibility of traditional approaches to consumer research: the exclusion of nonconscious effects, the laboratory-based study environment and the reliance on self-declarative methods. Based on the presumption that the study setting has an impact on consumers' responses and behavior also on a nonconscious level, eye-tracking methodology is proposed as an approach to objectively investigate consumer information processing and choice behavior in different study settings. The choice of the method is further supported by the fact that humans rely heavily on their sense of vision when interacting with the environment, and visual attention plays a crucial role in processing of marketing stimuli.

The following section introduces the topic and contributions of the three articles included in the dissertation. The empirical studies focus on: (1) the differences in spontaneous voluntary attention to stimuli presented as screen-images versus in their physical form, (2) the differences in consumer viewing behavior during choice process in different experimental setups, and (3) an improved method for visualizing eye-tracking data collected from mobile environments.

Chapter 2 focuses on the theoretical background and positioning of the dissertation relative to consumer research literature. To set the stage, a brief chronological overview of the development of marketing and consumer research disciplines is provided. In order to be able to explain the impact of contextual effects on consumer information processing and behavior, three constructs relevant to consumer psychology are discussed– perception, motivation and affect. It is argued that consumer information processing is based on the interplay between perception, motivation and affect, and each of these processes is influenced by environmental factors. It is followed by a brief review of marketing studies applying eye-tracking methodology, further substantiating the choice of the method.

The chapter on methodology discusses the schism between positivist and postmodern approaches in consumer research and describes the philosophical position of critical realism, which guides the work presented in this dissertation. Also the methodology for the articles and general delimitations are presented.

Chapter 4 presents three articles that are based on eye-tracking methodology and focus on the aspect of validity in consumer research. Article 1 takes as point of departure the spontaneous voluntary viewing behavior, and reveals that the stimulus presentation method, i.e. physical vs. screen-based display, significantly influences consumer viewing behavior and information processing. Article 2 investigates consumer choice process and finds that the relative impact of stimulus-driven versus goal-oriented factors in guiding attention is affected by the study setup and the confounding factors inherent to it. Shedding light on the impact of the experimental context on consumer behavior, the empirical findings have important implications for both researchers and practitioners. With regards to the aspect of external validity, they underline the importance of considering the study setting as a factor influencing consumer responses and behavior.

Article 3 focuses on the aspect of visualizing eye-tracking data collected from three-dimensional environments. In mobile settings the viewers' distance and viewing angle have an impact on how high acuity information is acquired, and visualizations of eye-tracking data should take these variables into account. It is argued that treating all gaze points as equal results in distortions, which decrease the validity of the heatmap. The article proposes a method for constructing 3D heatmaps that visualizes the allocation of attention to the stimulus area more accurately.

The following section discusses theoretical, empirical, methodological and managerial contributions of the work presented in this dissertation. Also the research limitations are discussed together with proposals for future research.

5.1 Theoretical contributions

The first theoretical contribution is related to the manner in which the study context is proposed to influence consumer information processing and behavior. More specifically, while consumer behavior research has investigated the downstream effects of perceptional, motivational and affective processes on consumer behavior, to the author's knowledge the three-way relationship between the three constructs has not been utilized. The theoretical review and figure 4 (on page 27) illustrating the triangular relationship between perception, motivation and affect could serve as the basis for developing a more comprehensive research approach for investigating conscious and nonconscious influences on consumer responses and behavior.

Secondly, the dissertation contributes to the acknowledgement of the relevance of measuring visual attention in consumer research. As argued, visual attention is not merely passive reception of information, but instead, an active part of how consumers operate in an environment (Tatler, 2014). Thus, the dissertation demonstrates the utility and encourages the application of eye-tracking methodology when studying consumers' information processing and interaction with the environment. Also the reviews of visual attention literature presented in theoretical chapters and in the articles contribute to the general understanding of consumer information processing.

5.2 Empirical contributions

The empirical studies reveal important aspects about the effect of experimental context on consumer information processing and choice behavior. Article 1 finds that there are important differences related to how consumers view stimuli in their physical form versus on computer screen. Namely, when the stimulus dimensions differ markedly in the two conditions, as for product shelves and banners, then in physical display condition the spread of the gaze locations is more spatially restrained. However, when the scale of the stimuli is kept constant, then in physical display condition the participants view the pictorial element on packages longer, as compared to the screen-viewing condition where textual elements tend to attract more attention. Compared to the physical display, a screen-based display of stimuli may also lead to more rapid screening of the scene. These findings demonstrate the impact of the stimulus presentation method on consumer information processing, and thereby challenge the generalizability of the findings derived from screen-based studies to natural behavior.

Article 2 investigates consumer choice process in three experimental setups: in front of a computer screen, in the lab setting with a mock shelf and in a real-life supermarket. Acknowledging various confounding factors inherent to the different setups, the study finds that there are differences in the degree to which the findings established in the literature apply to the different experimental contexts. In the store condition the center of the display plays a smaller role in guiding attention than in the screen-viewing condition and also the attention allocated to different shelf levels varies across the three conditions. While in the screen-viewing and the store conditions a higher number of facings is positively correlated with the relative viewing time, in mock-shelves condition the trend is the opposite. These findings underline the importance of considering the study setup as a factor influencing consumer responses and behavior, and contribute to the discourse on external validity of laboratory-based findings.

Article 3 investigates the visualization of mobile eye-tracking data as Gaussian-based heatmaps. It demonstrates that when the viewers' distance and viewing angle in three-dimensional environments are not taken into consideration, then mapping the gaze points as equal can cause considerable distortions to the heatmaps. The article pinpoints the shortcomings of using the method developed for two-dimensional stimuli for analyzing the data collected in three-dimensional environments and draws attention to the validity of the eye-tracking data analysis and visualizations when studies are conducted in mobile environments.

5.3 Methodological contributions

Articles 1 and 2 apply different methods that allow to control the exposure time and accurately mark the moment of the stimulus onset in eye-tracking studies that involve naturalistic physical stimuli. When exposed to the product display and large banners, the studies are built upon a design where study participants are led to a dark room and the stimulus exposure time is controlled with turning the lights in the room on and off. The same method was applied by Mack and Eckstein (2011) in a study on visual search. In study 2 the experimenter used a sheet of cardboard to block the participants' view of the product presentation stand and mask the stimulus substitution. This method was also applied by Belardinelli, Stepper and Butz (2016) in a study on planning motor actions. To the author's knowledge, neither of these methods has been used in consumer research before. However, with the spread of mobile eye-tracking technology both in academic research as well as in industry, these methods could be successfully utilized in order to control the timing of stimulus exposure.

The most important methodological contribution in this dissertation can be regarded the proposal of the method for constructing three-dimensional heatmaps, presented in Article 3. By accounting for the viewers' distance and viewing angle, the method avoids distortions that accompany two-dimensional heatmaps. Furthermore, the method allows for automatic mapping of gaze points, thereby saving the researcher a large number of man-hours. The article also addresses the issue of the lack of standardized methods in eye tracking research. Namely, in order to avoid the ambiguity that various event-detection algorithms introduce, the proposed approach argues for the use of raw data rather than fixation data. As the method of constructing 3D heatmaps eases data post-processing and improves the validity of the visualizations, Article 3 makes an important methodological contribution to conducting studies in real-world environments.

5.4 Managerial contributions

From a theoretical perspective it is important that the practitioners acknowledge the shortcomings of the traditional approaches to consumer research. Relying on self-declarative methods, ignoring non-conscious effects or conducting studies solely in artificial settings can result in misleading findings, and therefore also erroneous decision making. As visual attention plays a crucial role in the processing and efficiency of marketing stimuli (Wedel & Pieters, 2008b), eye-tracking methodology can provide companies an opportunity to optimize their package designs and marketing materials. Furthermore, eye-tracking studies in real-life retail environments can shed light on naturalistic behavior when consumers interact with product displays, and investigate, evaluate and choose the products they buy. Such insights allow companies to improve their in-store visibility, and potentially increase their sales and expand the customer base.

As eye-tracking research among practitioners closely resembles that in academia, the theoretical, empirical and methodological contributions also apply to the research in the industry. It is important that practitioners acknowledge the impact of the study setting and contextual cues on consumer responses and behavior. Marketing research, especially when involving biometric studies, can take up a substantial part of the budget. However, if the study setup bears little resemblance to the conditions in which the consumers naturally encounter the marketing stimuli, the findings obtained may be of little utility.

Article 1 shows that information acquisition differs depending on whether the participants are exposed to screen images or to stimuli in their physical form, and Article 2 demonstrates that consumer choice process is greatly influenced by the experimental context. When testing package designs or consumer preferences, for example, it may be the case that in an artificial study setup the participants pay a lot of attention to informative value claims presented on the package, and also use that information in their decision-making process. However, when faced with an array of physical choice alternatives in a naturalistic setting, they may rely on other decision strategies and heuristics, and end up behaving very differently. Thus, this dissertation underlines the importance of considering contextual cues as a factor influencing the external validity of the findings and recommends studying consumer responses and behavior in naturalistic, rather than simulated conditions.

5.5 Future research

First of all, the theoretical review proposes a framework portraying consumer information processing as an interplay between perception, motivation and affect that is dependent on contextual cues. While the two-way relationships between these processes are supported by various findings in consumer research and social and cognitive psychology literature, the interplay between the three constructs could be further investigated. For example, consumer involvement (e.g. Laurent & Kapferer, 1985) can be regarded as a motivational process, but how can contextual cues influence the level of involvement and how does that in turn affect or depend on the interplay between perceptual and affective processes? Such insights could further improve the understanding of consumer information processing and its downstream effects on behavior.

The empirical studies presented in this dissertation only cover the responses to fast moving consumer goods (FMCG) category, which can be considered a low-risk low-involvement category where individual consumption habits and preferences play an important role. Further, the evaluation of food items comprises both hedonic and utilitarian considerations, which may vary across individuals. Therefore it would be important to test whether the findings presented in the empirical studies also apply for other product categories, such as more expensive consumer durables (e.g. consumer electronics) or items that are acquired solely for utilitarian purposes (e.g. household cleaning products). Similar research with other product categories would allow to assess the degree to which the contextual effects impact consumer responses and behavior more accurately.

Also the impact of different visual properties of stimuli in different setting deserves further research. Studies applying mobile eye-tracking methodology in real-life supermarkets have shown, for example, that shape and contrast dominate the initial phase of searching (Clement et al., 2013) and that there is a strong interaction effect between visual saliency and individual preferences that guides visual attention (Gidlöf et al., 2017). But how do different colors, fonts and other visual characteristics influence attentional processes, and are there also differences in terms of how they are attended in artificial versus naturalistic settings?

Furthermore, as attentional selection is strongly influenced by various intrinsic factors, it would be worthy of investigation how individual variables, including personality traits, values, and preferences impact consumer information processing and choice behavior, and whether contextual cues have a different impact on people with different characteristics. For example, a recent study by Hoppe and colleagues (2018) showed that eye-movements during everyday behavior can be used for predicting personality traits. Thus, establishing the link between various intrinsic factors and the manner in which consumers attend visual stimuli in different situations and contexts could further benefit the research on consumer information processing.

Finally, the findings of the empirical studies suggest that contextual cues have a nonconscious effect on consumer information processing and behavior. This phenomenon could be further investigated via the application of other biometric methods. For example, with regards to affective processes, it has been shown that phasic arousal responses are reflective of the intensity of consumers' emotional responses (Groeppel-Klein, 2005; Groeppel-Klein, Germelmann, Domke, & Woratschek, 2005). Accordingly, the analysis of electrodermal activity (EDA) responses could reveal whether artificial and naturalistic study settings have a different impact on consumer arousal. Furthermore, the application of electroencephalography (EEG) and the analysis of neural oscillations could provide more detailed insights in mental processes that accompany the processing of information in different situations and contexts. For example, alpha oscillations have been shown to play a key role in inhibition of non-essential processing (Klimesch, Sauseng, & Hanslmayr, 2007), and gamma activity has been found to increase during complex and attention-demanding tasks (Tallon-Baudry & Bertrand, 1999). Thus, when exposed to stimuli in different study settings, indicators of neural activity could provide a further understanding of the differences in mental processes that contextual cues induce.

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CO-AUTHOR DECLARATIONS

Co-author statement

Title of paper	*Computer screen or real life: comparing the allocation of visual attention in remote and mobile settings*
Journal and date (if published)	

1. Formulation/identification of the scientific problem to be investigated and its operationalization into an appropriate set of research questions to be answered through empirical research and/or conceptual development
Description of contribution: In this paper we employ eye-tracking methodology and investigate the differences in terms of how consumers allocate attention to visual stimuli in their physical form versus as screen images. First, we compare the viewing time on different areas of marketing stimuli that in real-life contexts have larger dimensions. We find that in physical viewing condition less attention is allocated to the areas lower in the visual field and fixations are less spread out than in the screen-viewing condition. Secondly, investigating visual attention to package designs, we find that viewers exposed to the stimuli in the physical display condition attend the pictorial element longer, as opposed to the screen-display of stimuli which facilitates longer viewing time on the textual elements and a more rapid screening of the scene. These findings can be considered as evidence that study setting has an important impact on consumer information processing, and serve as a call for caution for researchers and practitioners who attempt to generalize findings from screen-based eye-tracking studies to the viewing behavior in the three-dimensional world.
2. Planning of the research, including selection of methods and method development
Description of contribution: PhD student did majority of the work independently 70%
3. Involvement in data collection and data analysis
Description of contribution: PhD student did majority of the work independently 70%
4. Presentation, interpretation and discussion of the analysis in the form of an article or manuscript
Description of contribution: PhD student did majority of the work independently 90%

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Co-author statement

Title of paper	*3D heatmap in marketing research and marketing practice – validation of an integrating model*
Journal and date (if published)	

1. Formulation/identification of the scientific problem to be investigated and its operationalization into an appropriate set of research questions to be answered through empirical research and/or conceptual development
Description of contribution: In this paper we investigate constructs and methods for visualizing eye-tracking data as Gaussian-based heatmaps. We demonstrate that when the viewers' viewing angle and distance in three-dimensional environments are not taken into account, it leads to parallax error and invalid Gaussian values that distort heatmap visualizations and decrease their validity in capturing and communicating the allocation of visual attention. We present a novel method for mapping gaze points from a three-dimensional environment onto a three-dimensional heatmap and demonstrate its utility in an experimental research design. By providing an automated solution that accounts for spatial variations in viewers' location, the paper offers a solution for making the data analysis faster and more efficient while also improving the ecological validity of the results.
2. Planning of the research, including selection of methods and method development
Description of contribution: PhD student made a substantial contribution 50%
3. Involvement in data collection and data analysis
Description of contribution: PhD student made a substantial contribution 40%
4. Presentation, interpretation and discussion of the analysis in the form of an article or manuscript
Description of contribution: PhD student did majority of the work independently 70%

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