PhD Dissertation by Yuxuan Guo

Beyond "Seeing" and "Understanding": Characteristics of Ambient and Focal Processing in Complex Tasks

Abstract

Human eye movements are essential for visual perception. A complex interaction of different types of eye movements is required when performing different tasks, such as orienting in space, identifying objects, or interacting with other persons. In the context of active vision, the present thesis investigates characteristics of fixations and saccades, with particular focus on the relationship between these two parameters. Analyzing the duration of fixations and the amplitude of saccades during everyday activities can provide insights into the processing of visual information, allowing for a better understanding of what details of the environment receive attention and how such details are processed.

Time course analyses of eye movements during free exploration of naturalistic scenes often reveal a systematic increase in fixation durations together with a decrease in saccade amplitudes, a pattern that has been explained within the framework of the two visual systems approach, i.e., as a shift from ambient to focal processing. Short fixations and long saccades during early viewing periods are classified as an ambient mode of visual processing, which is concerned with spatial orientation and is related to simple visual properties such as motion, contrast, and location. Longer fixations and shorter saccades during later viewing periods are classified as a focal mode of visual processing, which is concentrated in the foveal projection and is capable of object identification and semantic categorization. Such shifts have been observed following changes in the visual environment, such as stimulus onsets, scene cuts, or activity changes, and are thought to support the formation of mental representations of the current environment. However, it remains unclear to what extent shifts between ambient and focal visual processing generalize beyond scene exploration and externally triggered visual events to more active forms of task processing and complex real-world behavior.

The aim of my thesis is to address this research gap by examining whether ambient and focal eye movement characteristics can be identified across different kinds of task engagement and levels of ecological complexity. To this end, I analyze temporal changes in fixation duration and saccade amplitude in three empirical studies that investigate ambient and focal

processing in the context of film viewing, active task solving, and real-world problem-solving. Across these studies, I examine whether the eye movement characteristics associated with ambient and focal processing extend from externally triggered changes in visual narratives to internally generated transitions during task performance and conceptual problem-solving.

Study I consists of two experiments investigating shifts between ambient and focal visual processing during authentic film viewing, proposing that these shifts help update mental representations and support the comprehension of narrative changes across shot transitions. Experiment 1 utilized the *studyforrest* dataset (Hanke et al., 2016), comprising eye movement recordings from 30 participants watching the 2-hour movie *Forrest Gump*. Analyses revealed decreased fixation durations and increased saccade amplitudes around scene cuts throughout the course of viewing, indicating a focal-to-ambient shift and suggesting that scene cuts elicit ambient viewing analogous to that observed following a new image onset. However, because scene cuts may involve both full-field visual discontinuities and situational changes that trigger the perception of an event boundary, Experiment 1 could not determine which aspects of editing discontinuity were associated with the observed attentional shifts. Experiment 2 addressed this limitation using a Film-Quiz paradigm, tracking eye movements of viewers watching various film clips containing film cuts (i.e., transitions from one continuous camera shot to another) classified according to different levels of semantic continuity and changes in shot perspective, thereby distinguishing conceptual/narrative from perceptual discontinuity. The results indicate that different types of film cuts are immediately followed by ambient exploration, highlighting the interplay between ambient and focal processing as a fundamental perceptual coding strategy across varying degrees of editing discontinuity in naturalistic, complex, dynamic visual narratives, independent of viewers' prior film knowledge. In addition, cuts appearing during a fixation substantially prolong the ongoing fixation.

In Study II, I investigated whether shifts between ambient and focal processing can also be identified in active task solving when no external visual event is given. To address this question, I designed a multi-step Rubik's Cube task that can be broken down into smaller sub-tasks performed serially. The time course of eye movements was analyzed at multiple levels of this Rubik's Cube task, including when there were no external changes to the stimuli but when internal representations of the task were hypothesized to change (i.e., switching between different sub-tasks). Results suggest that initial ambient exploration is followed by a switch to more focal viewing across various levels of task processing with and without external changes to the stimuli. More importantly, the present findings suggest that ambient and focal eye movement characteristics might serve as a probe for the attentional state in task processing,

which does not seem to be influenced by changes in task performance. Within this study, a methodological extension for distinguishing ambient from focal gaze behavior using the coefficient *K* was evaluated.

In Study III, I examined whether the interplay between ambient and focal visual processing identified in laboratory-based task solving can also be observed when people work on complex real-world tasks—and if so, when? Based on a re-analysis of existing data (Kaszowska, 2019) integrating concurrent think aloud and eye tracking protocols, the study related participants’ internal thinking models to the parameters of their eye movements while they planned solutions to an open-ended design problem in a real-world setting. The study hypothesized that switching between ambient and focal processing may be useful when problem solvers encounter difficulty that compels them to shift their conceptual direction and adjust their solution path. The analyses further considered the possibility that individuals may prefer different attentional strategies for information-seeking behavior, such as ambient-to-focal or focal-to-ambient, although focal-to-ambient processing was not evident. The results lend support to the postulation of ambient-to-focal processing around shifts in conceptual direction and suggest a significant prolongation of fixation at the beginning of such conceptual shifts.

In conclusion, my thesis extends previous research on ambient and focal visual processing by examining whether the associated eye movement characteristics can be identified beyond laboratory scene viewing settings. The findings show that ambient and focal processing characteristics are not restricted to controlled laboratory visual stimuli, but can also be observed in dynamic visual narratives, in active multi-step task performance, and, at least preliminarily, in complex real-world problem-solving. At the same time, the studies indicate that the expression of these processing characteristics depends on the structure of the situation under investigation and may be linked to different kinds of transitions, including film cuts, sub-task switches, and shifts in conceptual direction. Thus, this thesis provides a broader empirical foundation for understanding the relationship between patterns of eye movement and modes of attentional processing across increasingly complex and ecologically relevant contexts, thereby offering a basis for future research into ambient and focal attentional mechanisms at higher semantic and metacognitive levels of information processing during complex tasks. In this respect, eye tracking is likely to gain increasing relevance not only in the development of future applications, but also as an integral component of such applications.