# DEFINING, CLASSIFYING AND EVALUATING AMBIENT DISPLAY

by

Ben Shelton MIT (Advanced) (Newcastle)

A thesis submitted in fulfillment of the requirement for the degree of Doctor of Philosophy in Computer Science*

THE UNIVERSITY OF
NEWCASTLE
AUSTRALIA

December 2019

*This research was supported by an Australian Government Research Training Program (RTP) Scholarship

## STATEMENT OF ORIGINALITY

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision. The thesis contains no material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved embargo.

Ben Shelton

# Abstract

Since the definition of Calm Computing in 1996 many examples of Ambient Display technology have been documented. This existing knowledge commonly focuses on the design and development of these systems, although there are also smaller volumes of research relating to the classification and evaluation of the technology. Analysis of this research suggests of two gaps in existing knowledge.

Firstly is a gap related to how Ambient Displays can be best described and defined. Using a systematic longitudinal review, this study finds three reoccurring attributes of the technology which can be used to describe Ambient Display. They are: *modality*, *physical form* and *level of interaction*. This study uses these categories to analyse and classify over 450 Ambient Displays reported between 1996 and 2016. This analysis is supported with a meta-analysis of previous taxonomies to provide an in-depth description of the Ambient Display design space. The result of this process is a new set of simplified descriptors, a formal definition of the technology and a standardised set of design dimensions.

A second identified gap in knowledge relates to how the utility of Ambient Displays can be best evaluated. The systematic review finds that Ambient Displays are commonly evaluated with almost 70% of the systems being assessed in some capacity (n=320/459). However, these previous assessments are commonly implementation centric and subjective in nature with few based on more specific design dimensions. This gap in knowledge is addressed by considering measures of Cognitive Load that help assess the workload associated with the technology.

Assessment began using in-situ case study research and an existing Ambient Display called WaveWatch. A self-assessment measure of Cognitive Load, the NASA-TLX, was applied along with direct measures of how often participants noticed the presence of an Ambient Display. Seven participants in a real-world office environment experienced the display for a five-day working week, logging noticed events and recording perceived workload. Around 25% of all on-screen events were noticed while levels of perceived Cognitive Load were found to fluctuate between participants. Aligning perceived levels of Cognitive Load to the presence of an Ambient Display was found to be difficult due to the non-continuous nature of the self-assessment protocol and real-life office environment where the study occurred.

To address some difficulties with the self-assessment protocol of Cognitive Load the Dual Task paradigm was introduced. Objective assessment was achieved using a Detection Response Task (DRT) which is standardised in ISO 17488:2016. The DRT was applied through two laboratory studies where participants were required to complete a primary task, with and without the Ambient Display present.

In the first pilot experiment forty participants completed three primary tasks (Auditory Digital Span task, Visual Digit Span task and n-back task) while undertaking a DRT. The presence of a simulated Ambient Display was a between-subjects factor where half of all participants were exposed to a peripheral visualisation. Two major findings were suggested as a result of this study.

Firstly, it was found that Cognitive Load was able to be manipulated in a reliable manner as a result of increasing task load. Main task performance (Main Effect - $F(3, 114)=103.24$, $p<.001$) and Cognitive Load (Main Effect - $F(3, 114)=14.91$, $p<.001$) were found to be significantly imposed as an effect of increasing task load in the n-back task. This was not the case for the Digit Span tasks (Visual Span - $t(78)=0.51$, $p=.609$, $BF_{10}=0.26$, Auditory Span - $t(78)=0.58$, $p=.562$, $BF_{10}=0.27$) which were unable to impose Cognitive Load in a consistent manner.

Secondly, the presence of an Ambient Display was not found to result in a performance differential across experimental factors in attributes of main (Main Effect - $F(1, 38)=0.71$, $p=.406$, $BF_{\text{Inclusion}}=0.34$) or secondary task performance (Main Effect - $F(1, 38)=0.95$, $p=.336$). A secondary experiment was used to validate these results through a study based upon a between-subjects design. In total twenty-seven participants completed a dual task scenario twice. Once with an Ambient Display present and again without any peripheral visualisation in the experimental environment.

The n-back task was found to result in statistically significant increases in DRT Response Time (Main Effect - $F(3, 78)=21.84$, $p<.001$) and n-back accuracy (Main Effect - $F(3, 78)=93.15$, $p<.001$) as an effect of increasing task load. The presence of an Ambient Display was again found to not result in a performance differential between experimental conditions in the main (Main Effect - $F(1, 26)=1.38$, $p=.251$, $BF_{\text{Inclusion}}=0.30$) or secondary task (Main Effect - $F(1, 26)=0.01$, $p=.989$, $BF_{\text{Inclusion}}=0.14$).

In summary, this study represents a new contribution to the field of Ambient Display. Previous narrative reviews are built upon by the systematic longitudinal methods of this study which have resulted in a detailed analysis of the first two decades of the technology's development. This approach has allowed the creation of new knowledge regarding the definition of the technology and acts as a detailed resource analysing the theory and practice within the field allowing the identification of gaps within the existing knowledge.

Most prominently the research addresses a gap in the knowledge relating to the objective assessment of Ambient Display. This is achieved through integrating novel methods of continually measuring the workload imposition of the technology in real-time, which is identified as an underutilised approach within the existing knowledge and represents a new way of assessing common design dimensions of the technology.

## ACKNOWLEDGEMENTS

The writing of this thesis has been an incredible experience over the past several years in working towards expanding the existing knowledge and finding myself learning new skills which have proved to be invaluable in the research process, my professional and personal life. I would like to extend my sincere gratitude to several individuals who have made this research possible.

First is my principal supervisor Dr Keith Nesbitt. I have worked with Keith for what seems like many years now between my Masters and PhD thesis and continue to find myself learning from Keith's deep knowledge of Computer Science and the research process. Keith's continuous support throughout the writing of this thesis has been remarkable in helping guide the research towards new avenues and opportunities that have not yet been explored in the field.

Next I would like to extend my thanks to my co-supervisor, Associate Professor Ami Eidels. Ami's contribution to this thesis has been incredible through his expertise in the field of Cognitive Psychology which helped guide this work towards considering the applicability of Cognitive Load to the Ambient Display paradigm. Along with Ami, I would also like to thank Alex Thorpe in helping to support this research from a psychology perspective. Alex's advice on research methods and data analysis has been fantastic in enhancing my own skills and pushing this research forward.

Finally on a personal note I would like to thank my colleagues from the university's Marketing and Communications unit for their continuous support throughout the research process. I would also like to thank my partner Jessie and daughter Callie for their patience and support throughout the writing of this thesis.

# TABLE OF CONTENTS

## CHAPTER 2.2 - CLASSIFYING AMBIENT DISPLAY



## CHAPTER 2.3 - EVALUATING AMBIENT DISPLAY

# TABLE OF FIGURES

## CHAPTER 3.1 - MEASURING COGNITIVE LOAD



## CHAPTER 4.0 - CASE STUDY: SUBJECTIVE MEASURE OF COGNITIVE LOAD



## CHAPTER 5.0 - PILOT STUDY: DETECTION RESPONSE TASK



## CHAPTER 6.0 - SECONDARY STUDY: DETECTION RESPONSE TASK

# TABLE OF TABLES

## CHAPTER 1.0 - INTRODUCTION



## CHAPTER 2.0 - SYSTEMATIC LITERATURE REVIEW



## CHAPTER 2.1 - DESCRIBING AMBIENT DISPLAY

## CHAPTER 2.2 - CLASSIFYING AMBIENT DISPLAY



## CHAPTER 2.3 - EVALUATING AMBIENT DISPLAY

## CHAPTER 3.1 - MEASURING COGNITIVE LOAD



## CHAPTER 4.0 - CASE STUDY: SUBJECTIVE MEASURE OF COGNITIVE LOAD



## CHAPTER 5.0 - PILOT STUDY: DETECTION RESPONSE TASK

**CHAPTER 6.0 - SECONDARY STUDY: DETECTION RESPONSE TASK**