

# **DEFINING, CLASSIFYING AND EVALUATING AMBIENT DISPLAY**

by

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## **STATEMENT OF ORIGINALITY**

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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 -  $F(1, 38)=0.71, p=.406, BF_{Inclusion}=0.34$ ) 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 -  $F(1, 26)=1.38, p=.251, BF_{Inclusion}=0.30$ ) or secondary task (Main Effect -  $F(1, 26)=0.01, p=.989, BF_{Inclusion}=0.14$ ).

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.

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