# Visual Performance With Small Concave and Convex Displays

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**Objective:** In this study, we aim to investigate how users' visual performance with a small flexible display changes based on the direction (i.e., convex, concave) and the magnitude (i.e., low, high) of the display curvature.

**Background:** Despite the wide interest in flexible display materials and deformable displays, the potential effects of nonplanar display surfaces on human perception and performance have received little attention. This study is the first to demonstrate how curving affects visual performance with an actual flexible display (4.5-in. active-matrix organic light-emitting diode).

**Method:** In a series of three experiments, we compared the performance with a planar display to the performance with concave and convex display surfaces with low and high curvature magnitudes. Two visual search tasks were employed that required the subject to detect target letters based on their contrast (Experiments 1 and 2) and identity (Experiment 3). Performance was measured as the sensitivity of target detection ($d'$) and threshold time of the search, respectively.

**Results:** There were similar sensitivities for targets across the curvature variants, but the high-magnitude curvatures resulted in prolonged search times, especially for the convex form. In both of the tasks, performance was dependent on the display location, which was defined as the target's distance from the display center.

**Conclusion:** High curvature magnitudes should be avoided, even in small displays, because large local changes in visual stimuli decrease processing speed outside the central display.

**Application:** The findings have implications for the development of technologies, applications, and user interfaces for flexible displays and the design of visual display devices.

**Keywords:** flexible displays, handheld devices, user performance, visual search, letter identification

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## INTRODUCTION

The appearance and use of future display devices are not constrained by rigid display materials. Rapid advances in thin-film display technology, including the development of electrophoretic ink (E Ink) and organic light-emitting diodes (OLEDs), have already produced the flexible, paperlike displays of e-readers and mobile phones (e.g., LG G Flex, Samsung Galaxy Round). At the same time, these advances have created a base for radical changes in the designs of and interactions with future computing devices. Concepts and prototypes for bendable (Herkenrath, Karrer, & Borchers, 2008; Kildal, Paasovaara, & Aaltonen, 2012; Lahey, Girouard, Burleson, & Vertegaal, 2011; Schwesig, Poupyrev, & Mori, 2004), rollable (Pillias, Hsu, & Cubaud, 2013), foldable (Khalilbeigi, Lissermann, Kleine, & Steimle, 2012), and even self-actuated shape-changing display devices (Roudaut, Karnik, Löchtefeld, & Subramanian, 2013) have been introduced in recent years, and interaction based on the physical deformation of such devices has risen to the active focus of research (Herkenrath et al., 2008; Khalilbeigi et al., 2012; Kildal et al., 2012; Lahey et al., 2011; Lee et al., 2010; Pillias et al., 2013; Roudaut et al., 2013; Schwesig et al., 2004; Wightman, Ginn, & Vertegaal, 2011). It has been predicted that ultimately, portable display devices will contain lightweight, high-resolution, multitouch displays that can be bent, curved, rolled, or folded without damaging the display structure. These deformable displays present contents on a malleable surface that can be static (e.g., curved to a form) or changeable (e.g., curved for a certain purpose) via user-initiated or device-initiated deformation or both (Vertegaal & Poupyrev, 2008).

Despite the wide interest in flexible display materials, the potential effects of nonplanar