Impact of Advancing Age on Visual Perception: A Design Evaluation of the TechnoSystems Excite Run 700 Treadmill User Interface

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September 23, 2014

Introduction

The ability to perceive and react to stimuli within the environment is critical to a species' survival. Without this information, humans would be unable to hunt, gather, and reproduce, among other vital functions. Humans receive sensory input in a variety of forms, including auditory, tactile, kinesthetic, and visual (Kellogg, 2007). These signals are transduced and transmitted to the brain for both low and high level processing (Kellogg, 2007). Of the senses, vision is the primary and most efficient method of gathering information in most humans (Goodale, 1999).

Whether or not a visual stimuli, or signal, is detected depends on a range of variables that impact top down, goal-directed mechanisms, such as attention, and bottom up, stimulus-driven factors, such as contrast (McMains & Kastner, 2011).

This paper will focus on stimulus-driven visual perception, reviewing the mechanics and sensitivity of the human visual system, as well as variables that affect signal strength and detection, such as contrast, size, and color. Particular attention will be paid those aspects of visual perception that decline with advancing age, including visual acuity and contrast and color sensitivity. These insights will then be applied to an evaluation of the TechnoSystems Excite Run 700 Treadmill user interface (see Figure 1) with respect to the elderly user.

Figure 1

TechnoSystems Excite Run 700 Treadmill Build and User Interface

Signal Detection Theory

At any one time, there can be numerous stimuli vying for attention within the visual field. Green and Swets (1966) developed a perceptual decision making model that described this state, known as signal detection theory (SDT). In SDT, "signals" are either present or absent amidst constant background "noise" (Green and Swets, 1966). The ability to distinguish between signals and noise depends two factors: response bias, a measure of human expectancy and values, and sensitivity (Green and Swets, 1966). Sensitivity is a function of both the keenness of an individual's senses, or sensory acuity, and signal strength relative to noise (Green and Swets, 1966). As response bias involves top down processing, this paper will concern itself solely with the latter.

Sensory acuity

Visual sensory acuity can be better understood through an analysis of the human visual system. Vision is initiated when light enters the eye via a transparent outer covering called the cornea (Stone, 2012). The cornea and lens work to refract and focus the light rays onto the back of the eye, or retina, where they are selectively detected and absorbed by millions of photoreceptors called rods and cones (Frisby & Stone, 2010).

Cones are responsible for color vision and can be divided into three types: long, medium, and short cones (Frisby & Stone, 2010). These are sensitive to long wavelengths of light (e.g. red), medium wavelengths (e.g. green), and short wavelengths (e.g. blue), respectively (Stone, 2012). While cones are attuned to fine detail and function best in bright light, rods are sensitive to motion and perform best in dim light (Stone, 2012). Since the retina's periphery is primarily populated by motion sensitive rods, and the retina's center, or fovea, consists of cones, visual acuity, or the ability to resolve fine detail, is highest in the center of the visual field (Schwartz, 1999).

When activated, rods and cones transform light into electrical impulses that are sent to the brain for processing via the retinal ganglion cells of the optic nerve (Frisby & Stone, 2010). These signals first arrive in the primary processing centers of the brain and progress to areas responsible for more complex analysis, which enable the viewer to both identify the stimuli and gauge its spatial relationship within the environment (Shiller, 1999; Goodale, 1999).

Hubel and Wiesel conducted numerous studies to identify the receptive fields of individual neurons in the retina and determine which patterns of light hitting the rods and cones would trigger such a reaction (Hubel & Wiesel, 1959; Hubel & Wiesel, 1962; Hubel & Wiesel, 1968). These experiments involved inserting microscopic electrodes into the retinal and brain neurons of anesthetized monkeys and cats and measuring their activity when exposed to visual stimuli. Through these studies, Hubel and Wiesel (1968) discovered "feature detectors," specialized nerve cells that respond to specific types of visual stimuli, such as bars of light and edges. The ability of feature detectors to distinguish these visual traits is largely impacted by contrast (Crassini, Brown, & Bowman, 1988). Contrast is one of a number of variables that influence the second sensitivity variable in SDT: signal strength.

Signal Strength

Contrast

Arguably the most important determinant of signal strength is contrast. Contrast can be understood as the difference in the characteristics of an object, such as the brightness and color, that make it distinguishable from other objects or noise (Frisby & Stone, 2010). For contrast to be detected, the amount of difference between an object and its surroundings must exceed a threshold, known as just noticeable difference (JND) (Frisby & Stone, 2010).

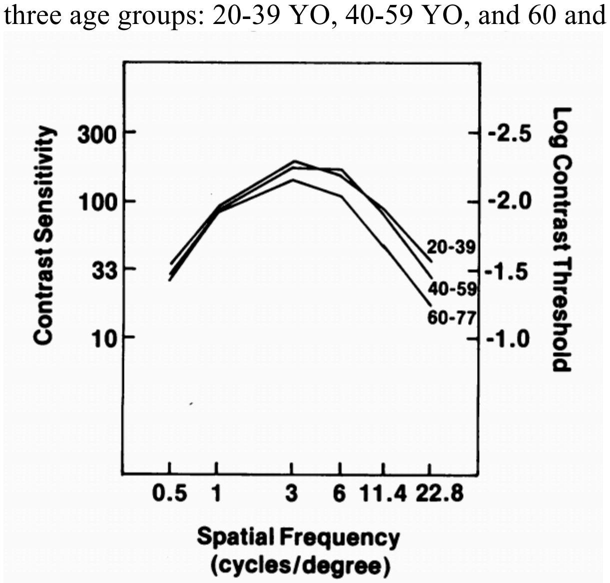
Contrast can be influenced by a number of variables, many of which become increasingly difficult to detect with age (Crassini et al, 1988; Scialfa, Garvey, Tyrell, & Leibowitz, 1992).

Size of Stimuli

One important factor in contrast detection is object size. Gratings, or repetitive patterns of alternating black and white lines of varying densities, are frequently employed to measure the smallest stimuli that an individual is capable of detecting (Campbell & Robson, 1967). Humans are most sensitive to detecting contrast when bar patterns occur around 4 cycles per degree (Campbell & Robson, 1968). As spatial frequency—the number of light/dark cycles per degree of visual angle—increases, contrast sensitivity decreases exponentially (Campbell & Green, 1965). While studies have shown that observers can detect a maximum of 60 cycles per degree, this sensitivity to higher spatial frequencies declines significantly with age (see Figure 2) (Owlsley, Sekuler, Siemsen, 1983; Owlsley & Sloane, 1987; Roorda, 2011).

Figure 2

Mean contrast sensitivity as a function of spatial frequency. Results are plotted separately for three age groups: 20-39 YO, 40-59 YO, and 60 and over. (From Owlsley & Sloane, 1987)



Numerous other studies have also shown a decrease in overall visual acuity with age (Pitts, 1982; Kline & Scialfa, 1996). This is at least in part due to the increasing rigidity of the lens (Gittings & Fozard, 1986).

Color

Color is another determinant of contrast and consists of three elements: brightness, saturation, and hue. Campbell and Green (1965) demonstrated the importance of brightness in contrast sensitivity through their grating experiments. Participants were shown gratings of decreasing brightness contrast until they were unable to detect the grating. The results indicated that gratings of greater brightness contrast were easier to detect, while the finest gratings could only be detected at high brightness contrast (i.e. black and white) (Campbell & Green, 1965).

Saturation can also affect perception of contrast. Studies conducted by Uchikawa, Uchikawa, and Kaiser (1984) have shown that saturated colors are perceived to be brighter than unsaturated colors (e.g. black, white, or gray), even if they are technically the same brightness. Therefore, like brightness, contrast between two objects increases as the differential in saturation levels increases.

Hue, or the wavelength of light (e.g. red), has a lesser but still noticeable effect on contrast. Mullen (1985) tested the impact of color on contrast detection by testing human visual acuity using red-green and yellow-blue gratings of equal brightness. With the exception of gratings with wide bars, contrast sensitivity using the colored gratings was lower than for monochromatic gratings (Mullen, 1985). Additionally, Mullen & Losada (1994) later gathered evidence that some degree of brightness contrast enables detection of hue contrast.

While hue appears to be less important to contrast than brightness, it still can play an influential role. For instance, due to chromatic aberration, some wavelengths of light are focused closer to the eye than others, such that red text on a black background appears to emerge from the screen (Mullen, 1985). However, as with contrast sensitivity and visual acuity, color sensitivity is susceptible to age-related decline. As Cooper, Ward, Gowland, and McIntosh (1991) demonstrated, discrimination between colors, particularly those at shorter wavelengths (e.g. blue), can prove very challenging for the elderly viewer.

Now that the pertinent factors influencing stimuli-dependent signal detection—sensory acuity and signal strength—have been established, these variables can be used to evaluate the design of the TechnoSystems Excite Run 700 Treadmill.

Use Case for TechnoSystems Excite Run 700 Treadmill

For the purposes of this evaluation, the user will be presumed to be a healthy adult male over the age of 60 who wears corrective lenses due to age-related vision decline. The environment in which this user is interacting with the treadmill is a brightly lit athletic center. As is the case with many corrective lens wearers, it can be presumed that the user will not wear his glasses while utilizing the exercise equipment and, as a result, will be operating within age-related vision capacity.

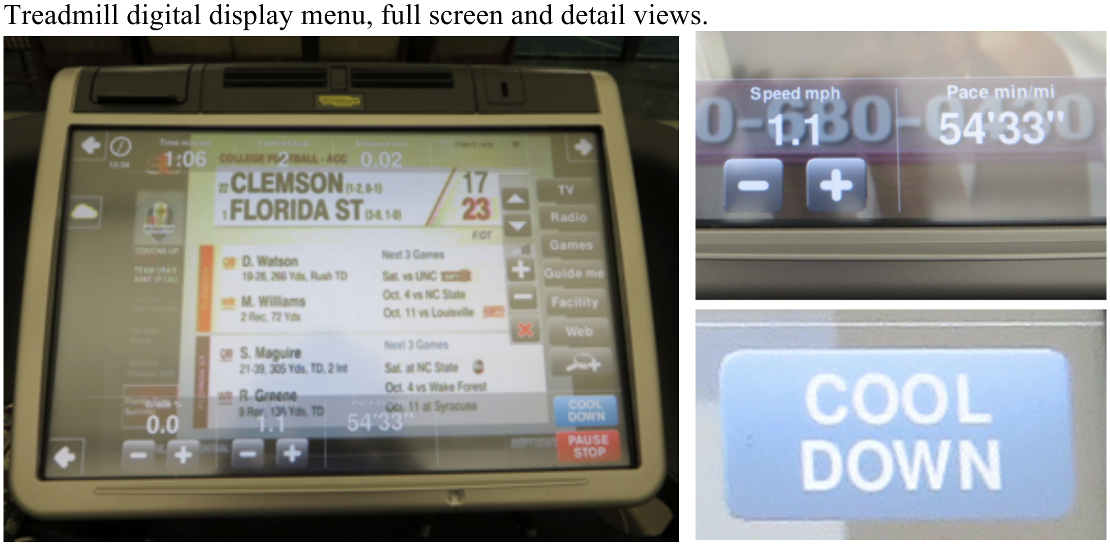
Design Evaluation

The TechnoSystems Excite Run 700 Treadmill presents a number of usability issues for the elderly user. This paper will solely focus on the high value components impacted by the age-related vision decline.

The functionality of the treadmill's digital user interface (see Figure 3) is essential to its usability. When operating a treadmill, most users are primarily concerned with belt speed, grade, and time. The user must be able to see and process these critical operational variables with ease. This is particularly important in the case of an elderly user, where a misguided tap of the screen, such as to the belt speed, could result in physical harm and liability issues.

Figure 3

Treadmill digital display menu, full screen and detail views.



While the large text size of the digital display seen in Figure 3 is in line with the diminished visual acuity of an elderly user (see Kline & Scialfa above), the white font and transparent menu prove problematic. Since the text is layered on top of a continually changing background (i.e. the TV screen) of varying brightness, saturation, and hue, the contrast of the white text is at times low (e.g. white text on light gray), at others high (e.g. white text on black). Additionally, the background noise created by the TV screen is considerable in comparison to the white font, resulting in a low signal to noise ratio. As Green & Swets (1966) noted, this leads to poor signal detection.

In contrast, the right side entertainment menu, in which white text is anchored over dark gray buttons, is more successful due to the greater degree of brightness contrast. However, given the low signal to noise ratio of the overall display controls, and Crassini et al.'s findings regarding age-related decreases in contrast sensitivity, the UI still merits modification.

For instance, the contrast of the digital display controls could be enhanced by changing the font color from white to black and anchoring the top, bottom, and rightmost menus on a thick white border spanning the periphery of the TV screen. This would require decreasing the dimensions of the TV viewing area, such that the critical controls would no longer encroach upon the TV picture. Inverting the color of the font from black to white will ensure maximum contrast and minimize issues of irradiation (Taylor, 1934). An alternative solution would be to relocate the time, calorie, distance, speed, grade, and pace indicators to an expanded plastic casing around the digital display, eliminating the contrast and noise issues associated with a transparent display, while also maintaining a large TV viewing area.

While the red "pause/stop" button with white font (see Figure 3) stands out due to hue and brightness-related contrast, as well as the illusory depth effects commonly associated with red, the blue "cool down" button is less successful (Uchikawa et al., 1984; Jackson et al., 1994). Since the saturation and brightness contrast between the white font and blue gradient background is minimal, this button is difficult for even a young, visually sharp user to perceive. This effect is further compounded by the fact that elderly users are less able to perceive blue light wavelengths, as evidenced by the work of Cooper, Ward, Gowland, and McIntosh (1991). Therefore, both the brightness and saturation contrast of this button should be significantly increased to ensure readability. Though color can enhance stimuli detection, as both Mullen (1985) and Mullen & Losada (1994) demonstrated, it should not be solely relied upon since factors such as brightness contrast often have a greater impact on contrast and, thereby, signal detection.

As with the digital display, the readability and signal strength of the emergency stop button is also crucial to operational safety (see Figure 4A). Though the saturated red color is appropriate due to its illusory depth effects and visibility under high luminance, the visibility and readability of the raised "emergency stop" text could be improved (Jackson et al., 1994; Frisby & Stone, 2010). Given the declining contrast sensitivity and visual acuity associated with advancing age, the low contrast, raised plastic labeling and small font could prove hard to read for the elderly user (Crassini et al., 1988; Kline & Scialfa, 1996). The design would benefit from larger font size, as well as exaggerated brightness, saturation, and hue contrast (see Figure 4B). These design modifications will result in more visible and defined edges, which can be more easily perceived by a user's feature detectors (Crassini et al., 1988; Hubel & Wiesel, 1959).

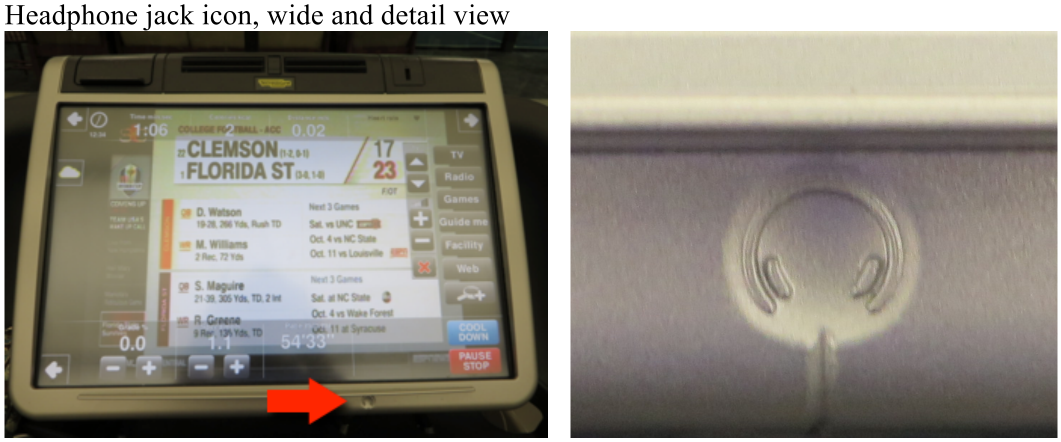
Figure 4

A) Emergency stop button B) Mockup of redesigned emergency stop button

Similarly, given the diminished visual acuity and contrast sensitivity noted above, the small, low contrast headphone jack icon (see Figure 5) could also prove difficult for an elderly user to detect. While not integral to the treadmill's basic operation and safety, the user's inability to perceive the jack would likely result in both frustration and loss of product functionality, negatively affecting the larger user experience.

Figure 5

Headphone jack icon, wide and detail view



Conclusion

Clearly, many variables are at play in signal detection. The key perceptual factors that determine whether a signal is differentiated from background noise, including signal strength and sensory acuity, are influenced by a number of sub-factors. Signal strength is impacted by such variables as contrast, size, and color, while sensory acuity is determined in large part by an individual's specific strengths and limitations, such as visual acuity and contrast and color sensitivity. This sensory acuity diminishes over time, particularly in individuals over the age of 60. By taking these age-related perceptual limitations into account and making the design changes indicated above, the usability of the TechnoSystems Excite Run 700 Treadmill could be greatly enhanced for the elderly user.

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