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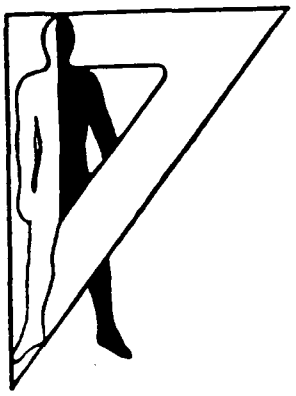

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THE INTEGRATION OF COMPLEX INFORMATON FROM AUDITORY AND VISUAL CHANNELS UNDER STRESS

Christopher D. Wickens
University of Illinois

May 1990
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This report describes research that was performed at the University of Illinois Aviation Research Laboratory. This research examined how the human operator's ability to integrate multiple channels of information is influenced by stress and by display formatting which brings channels of information closer. In a series of experiments, it was concluded that information integration is facilitated by combining formation channels into a single object display and by the use of common color. These manipulations do not necessarily facilitate dual task performance or focused attention. Some important distinctions in the creation of object displays are also described. It was also concluded that the use of common perceptual modalities (all visual) or spatial proximity does not enhance information integration ability relative to dual task performance. The use of a single hand to perform two integrated response actions can facilitate performance, particularly if one action is continuous and the other is discrete. In some studies, the effects of mild stressors were imposed to enhance benefits associated with multi-task auditory displays and to enhance the benefits of object displays.

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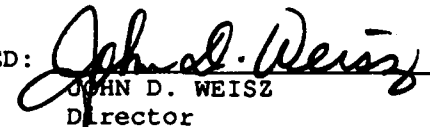
APPROVED: 

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CONTENTS

THE INTEGRATION OF COMPLEX INFORMATION FROM AUDITORY AND VISUAL CHANNELS UNDER STRESS

OVERVIEW

The goal of this research project was to examine how people integrate information from auditory and visual channels during stress. Thus, two overlapping foci were the process of information integration and the effects of stress. First, the guiding principle behind the research about information integration was the proximity compatibility principle. This principle, whose implications have been examined in many experiments, proposes that information sources that require "mental proximity" (either because they need to be integrated to perform a task or because they impose similar cognitive transformations) will be enhanced by more integrated or proximal display sources. In contrast, information sources to be processed independently are better served by "separate" displays. Hence, the proximity compatibility principle describes a "crossover interaction" between task type (integration versus independence) and display proximity (close versus distant). Much of the research in this report examined different ways of operationally defining "separate" through the use of separate objects, separate modalities, spatial separation, or color differences. This project also considered proximity of responses, as varied by the use of common versus separate hands.

Stress, the second element of this research, was manipulated in some experiments to determine its effects on both information integration and independent processing, with close and distant displays. The goal in this research was not to mimic levels of stress that were typical of Army operations. Rather, by imposing milder levels of noise, risk, and work load, it was hoped to demonstrate trends in the data that might be extrapolated to those higher levels typical of operational conditions.

The following pages describe in narrative form the results of this research in the two primary foci: the proximity compatibility principle and the stress effects. The appendix presents specific abstracts of the many experiments that were performed during different tasks described by the statement of work (SOW).

PROXIMITY COMPATIBILITY PRINCIPLE

Proximity of Display Modality

Two experiments examined whether two information sources could be better integrated if both sources were visual (high display proximity) or if they were presented in two separate modalities (auditory and visual). Pamperin and Wickens (1987) required subjects to interpret the spatial orientation of two of a set of rotating vectors, on the basis of a discrete display (auditory or visual). They failed to find consistent evidence that performance was better when the vector and the discrete display were both presented visually. Goettl and Wickens (1989) examined whether the direction of motion of a visual tracking cursor could be more rapidly controlled if the command information to initiate that control were presented audibly or visually; they reached a similar conclusion: information integration was not helped by common modality presentation. Both experiments contained dual task control conditions in which essentially the same dual channels of information were presented but now

required independent processing. In both cases, the data were ambivalent regarding whether dual task performance was better or worse with separate modalities.

Neither study's results supported the proximity compatibility principle since proximity is defined by modality. Both studies suggested that auditory presentation would not necessarily improve performance in the presence of a visual task. Goettl's research did, however, suggest that there was an advantage in using verbal channels (print or speech) to present information in a display that imposes heavy spatial demands. These results are consistent with the multiple resource theory (Wickens, 1990). The implications of these studies for other aspects of proximity and stress are described in the following paragraphs.

Object-Defined Proximity

Another way of creating proximity between two displayed sources of information, if they are both visual, is to integrate them as two dimensions of a single object. The traditional attitude display indicator is an example of such a display. The research emphasized object display principles because of the potential role that "decluttering" through object integration can accomplish in the high visual load environment characteristic of the rotorcraft cockpit.

Fracker and Wickens (1989) examined the benefits to be gained by integrating two axes of manual control as a single display object moving in two axes. An advantage was found and enhanced when the two axes of control had the same control dynamics. This second finding supports the proximity compatibility principle because the use of common control dynamics on two control axes facilitates a more integrated control strategy. The integrated control strategy is best served by the integrated display. Fracker and Wickens also observed a display-control interaction, suggesting that when there was compatibility between display and control proximity (both integrated or both separated), changes in control strategy were observed to indicate that greater control effort was mobilized for the task, and processing time was shorter. Another thrust of this experiment was to address two competing theories of dual task performance interactions. The results support a resource competition theory rather than an outcome conflict theory (Wickens, 1990).

The dual axis tracking study of Fracker and Wickens was followed by a programmatic series of studies by Carswell and Wickens (1988, 1989) that examined the proximity compatibility principle in the context of static graphical information displays. In a review of the literature about the graphical display of information, Carswell and Wickens concluded that the principle has been upheld; separate representations (e.g., bar graphs) better support independent graphical judgments and focused attention on separate display attributes, while integral displays (e.g., line graphs, polygons) provide better support for information integration. Although their review primarily covered graphs of data, its conclusions are equally applicable to multidimensional graphs such as engine parameters or tactical situations.

In the first of two experiments, Carswell and Wickens (1988) established an important distinction between two ways of combining features to make an object display. Heterogeneous dimensions are those that use fundamentally different perceptual analyzers, such as color and shape (Treisman, 1986), to create, for example, a colored bar. Homogeneous dimensions require the same

or similar perceptual analyzers for processing. For example, two identical dimensions of extent can be combined to create a rectangular object having height and width. Carswell and Wickens concluded that each object appears to have different properties: heterogeneous objects, such as the colored bar, offer more efficient parallel processing of its dimensions (color and length), regardless whether these dimensions are to be integrated or processed independently. In contrast, homogeneous objects offer emergent perceptual features, such as the shape or size of the rectangle, that can be creatively exploited by the display designer to serve a particular integration task but that appear to disrupt the ability to focus attention on the isolated dimensions necessary for independent processing. Carswell and Wickens determined that together, homogeneous and heterogeneous objects produce a different constellation of performance effects across tasks.

In the second experiment, Carswell and Wickens (1989) examined the distinction between object and separated displays and between homogeneous and heterogeneous objects. These displays were used in the service of four different tasks that varied in the degree to which independent processing versus information integration was required. Task variations included verifying, cross-checking, or comparing a series of instruments. The results provided a strong verification of the crossover interaction predicted by the proximity compatibility principle. They also indicated that homogeneous and heterogeneous objects were optimally suited for different information integration tasks.

Carswell and Wickens' distinction between homogeneous and heterogeneous dimensions provided an important foundation for two further object display studies. Wickens and Andre (1988) examined an object display designed to present critical parameters affecting aircraft stall probability. The information was meant to be prototypical of the multidimensional system monitoring task necessary in most aircraft. This study showed that the integration of the flight parameters, necessary to interpret information concerning stall, was better served by a well-configured homogeneous object display with emergent features mapped to stall probability than by a separated display. The object display, however, disrupted focused attention "check reading" of the individual flight parameters, again confirming crossover interaction of the proximity compatibility principle. The study also showed that a hybrid display incorporating a heterogeneous dimension (color) into the homogeneous object allowed subjects to improve their performance in focused attention without disrupting information integration. Use of the heterogeneous dimension to present each attribute of the object in a different color facilitated parallel processing.

Zhang (1989) examined the dual task resource costs of processing multidimensional information from separate displays and object displays that were either heterogeneous (colored bars) or homogeneous (rectangles). The displayed variables represented information about a potentially hostile threat in a simulated flight task. A dual task load was imposed by requiring subjects to devote most of their visual attention to a concurrent visual search task. The results indicated that the homogeneous object display (rectangle) with its emergent feature (area) best supported the integration task, while the heterogeneous object display least supported the integration task. The bar graph display was intermediate. For the focused attention task, the ordering of displays was reversed. These results reinforce the message that all objects are not alike.

Display Proximity and Color

A series of experiments described in Andre and Wickens (1989, 1990) and Wickens and Andre (1988) employed the aircraft stall warning task described previously, as a basis for examining the role of color proximity in the proximity compatibility principle. The hypothesis tested stated that the integration of stall parameters, presented in a cluttered display, will be facilitated if the parameters are presented in the same color (and different from the clutter). Correspondingly, the ability to focus attention on one indicator and ignore others will be facilitated by a unique color coding of each indicator. These predictions were upheld, whether the stall indicators were represented separately in space or were combined as dimensions of a single object.

Spatial Proximity

The stall paradigm of Andre and Wickens was also used as a vehicle for evaluating the role of spatial proximity in the proximity compatibility principle (Andre & Wickens, 1989, 1990; Wickens & Andre, 1988). Three indicators specifying values of the critical stall parameters were positioned at three different spatial separations from each other. The results revealed that proximity neither facilitated integration nor inhibited focused attention, relative to greater separation. However, when the display contained irrelevant clutter, an important conclusion was that proximity between relevant and irrelevant display items disrupted both focused attention and integration performance. Furthermore, this effect followed a linear relation with the mean distance between relevant and irrelevant displays, thereby providing the foundation for a computational model of display clutter.

The finding that manipulation of spatial proximity between relevant displays did not create the critical interaction predicted by the proximity compatibility principle, was also obtained in an experiment by Pamperin and Wickens (1987) described previously. This experiment observed that moving the two relevant indicators closer together in space had little or no effect on either focused attention or integration. Hence, it appears that proximity in space, like similarity of input modality, does not drive the proximity compatibility principle. The primary importance of space in information integration and focused attention appears to be in separating relevant from irrelevant material.

Response Proximity

If information integration may be facilitated by enhancing certain aspects of display proximity, is it also the case that integration tasks, in which a single or integrated cognitive activity requires two responses, are better served by proximal or similar responses? The best characterization of response proximity is when the responses for two related activities are assigned to the same hand. This may characterize a two-axis joystick, a hands-on throttle and stick (HOTAS), or the engine adjustments configured on the rotorcraft collective. Two experiments, whose display integration characteristics were previously described, examined the implications of the proximity compatibility principle for response integration. The first study of dual axis tracking by Fracker and Wickens (1989) asked two research questions: (a) would the use of a single two-axis control stick be beneficial in comparison to separate sticks (since a single integrated display was beneficial); and (b) would the benefits of a single control be enhanced (or

the costs reduced) if the dynamics of the two tracking axes were identical? (Identical dynamics imply integration of the two information processing characteristics.) The answer to the first question was "yes;" a benefit was obtained for single two-axis control. The answer to the second question was "no;" this benefit was not enhanced for identical rather than separate dynamics.

The second experiment to examine the role of response proximity in the proximity compatibility principle was the study by Goettl and Wickens (1989) in which discrete directional information was presented concurrently with a continuous two-axis manual control task. In the information integration condition, the discrete information was relevant to the tracking task; in the dual task condition, the discrete information was irrelevant to the tracking task but demanded an independent response. When the discrete information was relevant to tracking (integration), this information was classified more accurately if the task required acknowledgment with a trigger press on the same hand that was tracking. When the discrete information was independent of tracking, response was more accurate with the opposite hand.

Hence, results from this aspect of research offer partial support for response integration. When a discrete response pertains to a continuous manual control task, there is some benefit to be gained by assigning that response to the same hand as the control task.

STRESS EFFECTS

Two of the previously described studies have imposed mild manipulations of stress designed to establish how the display attention interactions were modulated by this variable. The objective was to extrapolate from the results toward the higher levels of stress more characteristic of extra laboratory operational tasks. In the first of these studies, Pamperin and Wickens (1987) imposed time stress and risk stress on subjects as they performed the vector processing task described briefly in the Proximity of Display Modality section. In this task, subjects monitored an array of rotating vectors while responding to alphanumeric information presented visually, close to or distant from the vectors or presented audibly. For integration trials, this information identified pairs of vectors to be compared. For dual task trials, the alphanumeric information was independent of the rotating vectors, and separate responses were required for the two stimulus channels (vectors and alphanumerics). During stressful conditions, both tasks were presented at a rapid rate, and financial risks were imposed by offering subjects a large sum of money that could be depleted by poor performance.

The pattern of results was fairly complex but may be best described by the following conclusions: (a) stress did not appear to induce significant visual tunneling in a way that the distant visual display was disrupted more than the close visual display; (b) stress disrupted visual performance more than auditory performance (across both integration and dual task trials); and (c) stress disrupted information integration more than dual task performance. The second of these conclusions appears to be particularly important, indicating that potential advantages of offloading information to the auditory modality may be enhanced during higher stress conditions.

In one of the experiments described in the Object-Defined Proximity section, Zhang (1989) examined the integration of information from a bar graph display and from heterogeneous and homogeneous object displays during two

levels of stress: (a) stress imposed by concurrent visual task demands and (b) the added stress imposed by 85-dB noise. The latter has been modeled by Hockey (1986) to provide effects on information processing that exactly mimic those obtained by the high anxiety that may be characteristic of combat situations (Berkun, 1964). In Zhang's task previously described, subjects integrated threat-relevant parameters from separate bar graph displays or from heterogeneous or homogeneous object displays. The results indicated that task loading had a nonmonotonic effect. As modest levels of work load were imposed, performance advantages of the homogeneous object display, with its emergent features, were enhanced. As work load was further increased, the difference between displays declined but was still statistically reliable. The effect of noise was to improve dual task performance of both object displays and degrade performance with the separate bar graph display. These latter results are consistent with a "tunneling" effect of noise, in which tunneling is defined by objects rather than by space.

CONCLUSION

It must be acknowledged that neither of the experimental manipulations of stress described was "strong" in the sense that they approximate the conditions imposed during combat when life is at risk. However, subjects in the experiments were sensitive to the manipulations imposed and rated the designated conditions as more stressful. Furthermore, the differences between display formatting that emerge as stress are varied at lower levels used in the laboratory experiments, and should maintain or perhaps further enhance at higher levels of operational stress. In this research, these differences were related to the reduced performance cost (or increased benefit) of audible displays and the advantage of homogeneous object displays.

THEORETICAL REVIEW

One final piece of work performed under this contract was a review of the properties of resources in multiple task performance, written as a chapter for a book on attention (Wickens, 1990). This review places the resource concept in the broader context of three other mechanisms of dual task interaction: switching, confusion, and cooperation, and is based extensively upon Fracker and Wickens' (1989) results.

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APPENDIX

COMPLETED WORK

COMPLETED WORK

The following section is organized according to the six tasks listed in the SOW. Publications that were completed are listed within each section, along with an abstract. When a given experiment generated more than one publication (e.g., a technical report and journal article), only one abstract is given.

Dual Axis Tracking

Name: Martin L. Fracker and Christopher D. Wickens

Title: Resources, confusions, and compatibility in dual-axis tracking: displays, controls, and dynamics. Journal of Experimental Psychology: Human Perception and Performance, 1989

Abstract: Why do people often find that performing two tasks at once is harder than performing one task at a time? Three mechanisms of task interference that might answer that question were investigated: resource competition, confusions, and incompatible task proximity between processing stages. The subjects performed dual-axis compensatory tracking with error displays that were either integrated or separated, with axis controls that either were integrated into one stick or remained separate, and with control dynamics on the two axes that were either the same or different. Tracking error increased and control activity decreased as a function of the combined difficulty of the two control dynamics. Integrated displays and integrated controls both led to increased confusions between tracking axes although error was not reliably affected. Significantly, performance was also affected by whether the integrality of displays matched that of controls. These results suggest that resource competition, confusions, and compatibility of proximity play distinct roles in dual-axis tracking performance.

Stress and Cognitive Tunneling

Name: Kenneth L. Pamperin and Christopher D. Wickens

Title: The effects of modality and stress across task type on human performance. Proceedings of the 31st Annual Meeting of the Human Factors Society, 1987

ABSTRACT: This investigation integrates four approaches to the study of attention and multiple task performance, to include the effects of stimulus modality presentation, the influence of spatial separation in visual stimulus presentation, the effects of stress, and the influence of task type (dual-task versus information-integration task), in a spatial vector monitoring task. A significant benefit of cross-modal (visual-auditory) presentation was found when information was integrated at both levels of stress, while an interaction between modality and stress level occurred in the dual task condition, favoring the intra-modal (visual-visual) presentations at the lower stress

level. The auditory display tended to be more stress resistant. The results support Kahneman's concept of stress-related resource expansion, provide weak support for perceptual narrowing, and provide little support for a processing modalities dimension of the Multiple Resource Model. Instead, they are consistent with the concept of auditory pre-emption, discussed by Wickens (1987).

Cognitive Tunneling in the Cockpit

Name: K. Zhang

Title: Effects of noise and work load on performance with object displays versus separated displays. Unpublished Ph.D. dissertation, University of Illinois, 1989

Three central displays (a homogeneous object display, a heterogeneous object display, and a separated display), three work load levels of peripheral search task (none, low, or high work load), and a noise stressor were employed in this study to examine the influence of stress in integral versus separable display formats. Homogeneous objects were defined by the height and width of a rectangle, heterogeneous objects by the height and color of a bar, and separate displays by two vertically aligned bar graphs. Response time, mean error, search accuracy, and rating scales of difficulty and stress were recorded as dependent variables. The important results of these experiments are as follow:

1. Response latency was sensitive to the manipulation of display format, while accuracy was relatively insensitive to the manipulation. Based on the response time, the homogeneous object display was the best display for integrating information. The heterogeneous object display was least supported. The response time by the separated display was between these two extremes. The effect of display format in the response time was statistically significant ($F(2,26) = 8.24$, $p < 0.01$).

2. The heterogeneous object display was the best one for focused attention tasks, the homogeneous object display was least supported, and the separated display was intermediate. The difference in response time was significant ($p < 0.001$). There was no significant effect of display format in mean errors (experiments 1 and 2).

3. The manipulation in work load significantly affected subjects' performance in both the search task and the central decision-making task. The measurements of all the dependent variables decreased with the increase of the work load (experiment 1).

4. Although there was no overall interaction in work load and display format in response time, the display format affected the response time the most at the intermediate work load level ($p < 0.01$). At this level, there were significant differences between the homogeneous object display and each of the other two displays. The display effect was marginally significant during the single central decision-making condition ($p = 0.13$). The display

effect was significant during the high work load condition ($p < 0.05$). At this level, the only significant difference was between the homogeneous object display and the heterogeneous object display (experiment 1).

5. Noise had no overall effect on the performance of either the central decision-making tasks or the search task. There was, however, a significant interaction of noise and display format in the accuracy of the search task ($p < 0.01$). Accuracy with the object displays was improved during the noise condition, while accuracy with the separated display was lowered during the noise condition (experiment 2).

6. Subjective measurements were sensitive to the manipulations in work load and noise. Rating scales of difficulty and stress were increased significantly with the increase in work load. The noise conditions were significantly more stressful and difficult than the quiet condition. The subjective measures were not sensitive to the manipulation of the display format.

Task Integration of Discrete and Continuous Information

Name: Barry P. Goettl and Christopher D. Wickens

Title: Information integration and response proximity in the performance of a manual control task, University of Illinois Institute of Aviation, 1989.

Abstract: An information integration hypothesis proposed by Wickens and Boles (1983) maintains that when task-relevant information must be integrated by the operator, such information should be configured to maintain proximity. Proximity may be defined at the input stage as shared resources or as response proximity; subjects performed a manual control task in that discrete information was integrated with the manual control task. Four different display formats were manipulated within subjects, and two response configurations were manipulated between groups. It was predicted that (a) cues most similar to the tracking task (i.e., visual and spatial) would be processed most efficiently and result in fast adaptation; and (b) detection with the hand performing the tracking task would be faster and more accurate.

By comparing this group with a group of subjects performing a dual task designed to have similar processing requirements, support was obtained for the integration hypothesis with regard to response proximity but not display proximity. Performance in the integration task was improved when the integrated stimuli were responded to with the tracking hand than with the non-tracking hand. The influence of display modality was interpreted in terms of attention switching, and the effect of display code supported a resource competition interpretation. Implications of these findings are discussed and applied to the realms of high performance aircraft.

Name: Barry P. Goettl and Christopher D. Wickens

Title: Multiple resources versus information integration. Proceedings of the 33rd Annual Meeting of the Human Factors Society, 1989.

Abstract: The present study investigates the applicability of an information integration hypothesis developed by Wickens and Bole (1983), to display format and response configuration. Twenty paid subjects performed either a dual-task or an integration task. The tasks were similar in all respects with the exception of information integration requirements. Proximity was manipulated via display format and response configuration. Results of the display format manipulation supported a multiple resources interpretation while the effects of response configuration were consistent with the integration hypothesis. These results point to a possible limitation in applying the integration hypothesis to resource demands of displays, but suggest that the hypothesis may apply to response configuration.

Response Proximity

Fracker and Wickens (1989) see Dual Axis Tracking

Goettl and Wickens (1989) see Task Integration of Discrete and Continuous Information

Decision Aiding

Name: C. Melody Carswell and Christopher D. Wickens

Title: Comparative graphics: history and applications of perceptual integrality theory and the proximity compatibility hypothesis. U.S. Army Human Engineering Laboratory, Technical Memorandum 8-88

Abstract: Interest has been recently renewed in the development and use of graphic displays for situations requiring the timely assimilation of large amounts of quantitative information. The present report traces the development of many of the graphic formats in common use today and reviews the experimental literature that compares alternative techniques. The proximity compatibility hypothesis is used to integrate the experimental work and is recommended as a framework to guide future experimentation and design decisions. Research issues regarding the appropriate functional classification of graphical formats--the designation of "graphical proximity"--are also discussed.

Name: C. Melody Carswell and Christopher D. Wickens

Title: The perceptual interaction of graphical attributes in thirteen bivariate displays integral. U.S. Army Human Engineering Laboratory, Technical Memorandum 22-89.

Abstract: Thirteen graphical formats, each designed to display two variables, were subjected to performance-based diagnostics of integrality, configurality, and perceptual unity. None of the graphs appeared to be composed of integral dimensions; however, several graphs were classified as unitary or configural. When graphical elements or dimensions were combined into a single object, they tended to be associated with the unitary pattern of performance. Homogeneous object displays tended to be associated with configural outcomes.

Name: Christopher D. Wickens and Anthony D. Andre

Title: Proximity compatibility and information display: effects of color, space, and objectness on information integration. Proceedings of the 32nd Annual Meeting of the Human Factors Society, 1988.

Abstract: The proximity compatibility principle asserts that two or more channels of information that must be integrated in the performance of a task are better served by closer display proximity. Separate channels upon which attention must be focused are better served by more separated displays. We report a series of four experiments that examine this principle in the context of a simulated aircraft stall warning indicator. The experiments manipulate display proximity in terms of color similarity, spatial closeness, and object integrality. Information about three variables that contribute to the likelihood of aircraft stall is presented on a cluttered display on trials that either require their integration, or require focused attention recall of a specific value. The results indicate that color similarity and object integrality adhere to the proximity compatibility principle, but that spatial proximity does not. Instead, the spatial variable that most strongly influences performance is the spatial proximity between relevant and irrelevant information, and this proximity degrades focused attention and integration trials to the same degree. The results also indicate that an appropriate mixture of color coding and object integrality can improve the accuracy of both focused and integration tasks, but at the expense of time. The data are discussed in terms of their practical implications for multi-element display design.

Name: Anthony A. Andre and Christopher D. Wickens

Title: Proximity compatibility and information display: the effects of space and color on the analysis of aircraft stall conditions. U.S. Army Human Engineering Laboratory, Technical Memorandum 16-89

Abstract: The proximity compatibility principle (Wickens, 1987) asserts that when a task requires the integration of multiple sources of information, performance will be best supported when that information is displayed in close proximity. Conversely, when a task requires attention to be focused on a

specific source of information, performance will be best supported by a more separated display. To assess the validity of this principle, a series of three experiments were conducted in which subjects monitored a display of flight parameters critical to aircraft stability and were required to either predict the likelihood of an aircraft stall (information integration), or to recall the value of a single flight parameter (focused attention). Display proximity of relevant information was imposed through spatial closeness and color similarity. The results indicate that color adheres to the proximity compatibility principle, but that space does not. Instead, the spatial proximity between relevant and irrelevant information appears to be the dominant factor affecting performance across both tasks. The data are discussed in terms of their practical implications for multi-element display design.

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Title: Information processing and perceptual characteristics of display design: the role of emergent features and objects U.S. Army Human Engineering Laboratory, Technical Memorandum 7-90.

Abstract: In this report, the fundamental theoretical and applied principles are outlined, which have been cited to justify the relative benefits of object displays, the representation of several quantitative variables as features of single geometric object. In particular, the proximity compatibility principle is described, which asserts that object displays will facilitate information integration tasks, but disrupt tasks that require focused attention on the individual dimensions of the object. Finally, an experiment is described contrasting three displays: a monochrome object, a multicolor integrate or focus attention on one of three sources of display information in an aircraft stall judgment task. Evaluation of the monochrome object revealed superior integration performance but degraded focused attention performance relative to the bar graph display, thus illustrating the proximity compatibility principle. The multicolored object, in contract, emerged as a display concept that could potentially support accurate integration and focused attention performance, highlighting the role of emergent features and color coding, and suggesting some modifications of the proximity compatibility principle. The results are discussed in terms of their theoretical and practical application to multi-element interface design.