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AGE-RELATED DIFFERENCES IN COMPLEX MONITORING PERFORMANCE

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16. Abstract

The present study examined the effect of age on the ability to sustain attention to a complex monitoring task. The visual display was designed to resemble an air traffic control radar display containing alphanumeric symbols. Subjects in age groups 18-29, 40-50, and 60-70 years were tested over a 2-hour session. Sixteen symbols appeared on the screen at all times, with 10 critical stimuli (a designated change in the alphanumerics) occurring during each half-hour. Performance decrement was significantly related to age, with performance declining earlier in the session in the oldest group of subjects. Recordings of eye movement activity, skin conductance level, and subjective assessments of fatigue, boredom, monotony, and attentiveness generally failed to reveal any clear reasons for the greater performance decrement of older subjects. Possible directions for further research are discussed.

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AGE-RELATED DIFFERENCES IN COMPLEX MONITORING PERFORMANCE

Introduction.

Effective monitoring of complex visual displays, such as the cathode-ray tube (CRT) displays used in air traffic control radar systems, requires the ability to detect relevant stimulus changes rapidly, usually in the presence of many irrelevant and/or competing stimuli (selective attention), and the ability to maintain a high level of attention to the visual display over prolonged periods of time (sustained attention). It has recently been argued that these two forms of attention, i.e., selective and sustained, are not only quite different conceptually, but may reflect brain processes that are neurologically distinct (8).

Evidence is accumulating that selective attention, as it relates to the ability to detect task-relevant visual information in the presence of task-irrelevant information, is significantly impaired as a function of age. In a study by Rabbitt (14), for example, subjects (Ss) in their 20's or 70's were required to sort cards containing either an A or a B into two separate stacks. Four levels of difficulty were employed in which different packs of cards contained 0, 1, 4, or 8 additional irrelevant letters. Sorting time was found to increase with age as the number of irrelevant stimuli increased. In addition, a significant age by packs interaction indicated that sorting times for older Ss increased more sharply than did times for younger Ss as the number of irrelevant stimuli increased.

Farkas and Hoyer (4) have recently examined the age-related effects of a different variable, perceptual grouping, on selective attention. Ss in three groups with mean ages of 22.13, 46.75, and 69.38 years were required to sort decks of cards containing either no irrelevant information, contrasting irrelevant information, or similar irrelevant information. Each card contained either an upright or inverted letter T (target item) located in one of the four squares of an imaginary 2 x 2 matrix. The other three squares were either empty (no irrelevant information), contained the letter I's that were all in the same vertical plane as the T (similar irrelevant information) or contained I's that were displaced 90° relative to the T (contrasting irrelevant information). Ss sorted cards from each of the three types of packs into separate stacks according to the orientation of the target letter. Sorting time was greater for all age groups in the presence of similar than in the presence of contrasting, irrelevant information. In general, however, the oldest group was impaired the most by both types of irrelevant information.

The above studies of selective attention clearly reveal age-related impairments in the ability to detect well-defined task-relevant information in the presence of task-irrelevant information. Evidence supporting an age-related change in sustained attention (vigilance), however, is far more equivocal. In one of the earliest studies of age and vigilance performance, York (20) failed to find any differences between groups with mean ages of 30, 50, and 70 years in their performance of a simple visual vigilance task involving the detection of infrequent double flashes. Likewise, Griew and Davis (7) found no differences between groups with ages of 19 to 31 and 45 to 60 years in the number of correct detections using an auditory vigilance task requiring the detection of occasional sequences of three consecutive odd digits. A number of subsequent studies using essentially the same auditory task employed by Griew and Davis and employing comparable age groups also failed to find any differences in correct detections as a function of age (2,6,12,18,19).

On the basis of the above findings, one might reasonably conclude that sustained attention, as measured in conventional vigilance experiments, is not influenced by the aging process. Yet in 1964, Surwillo and Quilter (16) reported a vigilance study in which clear age-related differences were obtained. Ss ranging in age from 22 to 82 years monitored a Mackworth clock (11) for a period of 1 hour. This task requires Ss to detect occasional double jumps of a pointer that normally rotates in discrete, once-per-second jumps about a plain white clock face. Older (> 60 years) Ss detected significantly fewer signals than did the younger (< 60 years) Ss in this study. More interesting, however, was the fact that differences in vigilance performance were not present at the beginning of the task. The significant difference between age groups was the result of a much greater performance decrement among the older Ss toward the end of the session. A subsequent replication of this study confirmed these findings (15).

A possible explanation for the age-related differences reported by Surwillo (15) and Surwillo and Quilter (16) involves the vigilance task employed. Davis and Tune (3) have hypothesized that effective performance on the Mackworth clock requires continuous search, and the additional load imposed by this requirement may have affected older Ss more adversely than younger ones. If the greater performance decrement obtained for older Ss in the Surwillo studies resulted from this rather minimal search requirement, then vigilance tasks involving much greater visual search should show even more pronounced age differences in sustained attention.

The present study was conducted to investigate this possibility. The task employed resembled a contemporary air traffic control radar display and contained a constant number of alphanumeric data blocks. Ss from different age groups monitored the display over a 2-hour period for occasional "critical stimuli" consisting of designated changes in the alphanumerics. On the basis of the studies of selective attention reviewed earlier, it was expected that overall (mean) detection times on this task would be greater with advancing age. However, the results obtained by Surwillo would suggest that age-related differences in target detection time may occur only after some time period of task performance, with the onset of performance impairment occurring earlier among older Ss than among younger ones.

Besides studying performance effects, certain physiological and subjective measures were included in the present study. Skin conductance level was recorded to provide estimates of differences in arousal level, and electro-occulographic (EOG) recordings of horizontal eye movement activity were obtained to assess scanning activity. A third measure, average dominant electroencephalographic (EEG) frequency, was recorded but not analyzed because of instrumentation problems. The subjective measures included self-reported feelings of fatigue, attentiveness, annoyance, boredom, and monotony. It was felt that measures of subjective fatigue and boredom were particularly important to include, since it has been suggested that the age-related performance decrement reported by Surwillo (15) and Surwillo and Quilter (16) might have been due to greater task boredom and fatigue experienced by older Ss (5).

Method.

Subjects. Forty-five paid volunteer Ss (19 males and 26 females) participated in the experiment. Three age groups were represented (18-29, 40-50, and 60-70 years), with 15 Ss in each group. Mean ages within the groups were 21.7, 45.7, and 63.1 years respectively. Educational backgrounds varied from several years of high school to some graduate study. The most common "occupations" were college student, housewife, clerical-sales, and retired military/civil service. All Ss were in good health as determined from an interview that included questions concerning any regular usage of prescribed drugs or medication. In addition, all had normal visual acuity (corrected to 20/20 if necessary).

Design and Task Apparatus. All task programing and recording of responses were accomplished using a Digital Equipment Corporation PDP-11/40 computer interfaced with a 17-inch (43 cm) CRT. The CRT was located in a console resembling an air traffic control radar unit. The stimuli (targets) consisted of small rectangular "blips" representing the locations of given aircraft. Adjacent to each target was an alphanumeric data block. Data blocks comprised two rows of symbols: the top row, consisting of two letters and three numerals, identified the aircraft, while the bottom row of six numerals indicated its altitude and speed. The first three of these numerals gave altitude in hundreds of feet and the last three gave groundspeed.

A simulated radar sweepline made one complete clockwise revolution every 6 seconds. A target was updated as to location and any change in its data block moments after the sweepline passed the target's prior location. Targets normally moved in a linear fashion unless a course change was necessary to avoid target overlaps. Sixteen targets were present at all times; as one left, another appeared on the screen. The critical stimulus or signal to which the S was instructed to respond consisted of a change in a target's displayed altitude to a value greater than 550 or less than 150. The values of the increases or decreases in altitude were randomly determined, except that the changed altitude value could not be greater than 599 or less than 100. Ten such critical stimuli appeared in each 30-minute period; five occurred in the first 15 minutes and five in the second. The S's response to a critical stimulus consisted of pressing a button held in the right hand and then holding a light pen over the critical target. The light pen caused the altitude portion of the data block to revert to its previous value. If the S failed to detect a critical stimulus within 1 minute, the data block automatically reverted to its previous value. All performance data were recorded by the computer for subsequent processing.

Physiological Recordings and Instrumentation. Beckman miniature biopotential electrodes were attached directly above and below the right eye and at the outer canthi of both eyes. Leads from the vertical and horizontal pairs of electrodes were connected to two separate channels of a Beckman Dynograph and recorded with a 3.0-second time constant. These channels served as the two primary EOG channels and, because of the relatively long time constant, recorded both following and saccadic movements. In order to extract only the faster saccadic movements for computer processing, the output of the primary horizontal channel was recorded on a third channel by differentiating the EOG with a time constant of 0.03 seconds. (Only horizontal movements were computer-processed because of eyeblink artifacts in the vertical recordings.) The resulting positive and negative pulses were led to two Schmidt triggers set for positive and negative inputs respectively, an OR gate, and hence to one of the digital inputs of the computer. These input pulses were also displayed for monitoring purposes on a fourth channel of the Dynograph.

Beckman biopotential electrodes filled with a saline paste (10) and attached to the volar surfaces of the index and middle fingers of the S's left hand were used for measuring conductance level. Leads from these electrodes led to a Beckman Type 9844 coupler that recorded conductance directly.

The computer and other recording apparatus were located in an adjacent room from which the S was monitored via closed-circuit TV. Indirect lighting was used in the S's room, and the level of illumination at the display was 21.5 meter-candles. This level approximates that used in operational air traffic control environments.

Eye Movement Calibration. The gain of the primary horizontal channel on the Dynograph was initially adjusted to yield a 1-mm peak-to-peak deflection to a 50 μV, 1-Hz input signal from a Grass Square Wave Calibrator. The gain controls of the Schmidt triggers were then adjusted to just fire at the peak of each positive and negative excursion of the calibration signal. Following this, each S's horizontal as well as vertical eye movements were calibrated using an optical table with chinrest support. Ss were instructed to fixate points at 90° and 270° on the circumference of a 22-cm circle which subtended a visual angle of 20°. A similar procedure was followed for vertical eye movements, except that points at 180° and 360° were used. The gain controls of the primary horizontal and vertical channels were adjusted to yield peak-to-peak deflections of 2 cm as the eyes were deflected to the extremes of the circle. Thus 1 mm of pen deflection equaled 1° of eye movement. Any horizontal saccadic movement equal to or greater than this value caused an output from one of the Schmidt triggers.

Procedure. On arrival the S was taken to the experimental room, orientation instructions were given, the S was instrumented for physiological recording, and eye movements were calibrated. Then a 9-point subjective rating scale was administered dealing with present feelings of attentiveness, fatigue, annoyance, and boredom.

The S was seated in a straight-backed chair directly facing the console. The circular display area of the screen subtended a visual angle of approximately 20° at the S's viewing distance. The minimum separation of alphanumeric targets at this distance was approximately 2.4°. Although a rigidly fixed head restraint would have been desirable in order to eliminate head movements, this was not considered feasible in view of the length of the task session. Instead, each S was instructed to sit straight in the chair with his/her head directly facing the screen at all times. While this procedure is not optimal, since small head movements produce apparent eye movements indistinguishable from true eye movements, it was expected that error resulting from head movements would be randomly distributed across conditions and within Ss. Periodic observations revealed that virtually all Ss complied with instructions to keep gross head movements to a minimum.

The task instructions emphasized the necessity of pressing the button immediately upon detection of a critical stimulus. The S was told that a critical stimulus (any altitude value greater than 550 or less than 150) could occur in any target at any time, regardless of the current altitude values of the targets. It was explained that occasional large changes in altitude would not normally occur in an actual radar system, but that this departure from normal conditions was necessary to insure that all targets would be given equal priority in scanning. Following the taped instructions, the S was given a 4-minute practice period containing six critical stimuli.

After the 2-hour task session, the S completed a second form of the subjective rating scale. This form was identical to the first except that the S was asked to rate each item, plus one additional item dealing with task monotony, on the basis of how the S felt near the end of the test period just completed.

Measurement of the Performance and Physiological Data. Performance data were computer-processed and the following measures were obtained on each S for each 30-minute period (all latency measures refer to the time from critical stimulus onset to the button press):

(i) Mean response latencies to critical stimuli correctly identified.

(ii) Number of button presses without a critical stimulus.

(iii) Number of critical stimuli missed.

For eye movements, the computer identified each correct response (button press) and then determined mean fixation duration from the inter-saccadic interval data contained in the 30-second interval immediately preceding this response. (Mean fixation duration can also be considered an index of fixation frequency. Consequently, although the data were analyzed only in terms of mean fixation durations, subsequent discussions may refer to mean fixation duration and frequency of fixations interchangeably.) If a critical stimulus was missed, the 30-second interval prior to the time the stimulus timed out was analyzed. Average values derived from the above 30-second intervals were obtained for each 30-minute period. To eliminate various forms of electronic and/or physiological noise from the data, all apparent fixation durations of less than 100 ms were rejected by the analysis program.

Conductance levels were measured directly from the Dynograph recordings at half-hour intervals.

Results.

Performance Data. Figure 1 shows mean detection latencies across 30-minute periods for the three age groups. Analysis of variance applied to these data revealed significant ($p < .05$ throughout) main effects for age groups, $F(2/42) = 6.05$, for 30-minute periods, $F(3/126) = 12.01$, and for the age by periods interaction, $F(6/126) = 3.06$. To clarify the nature of the significant interaction effect, further comparisons were made. Newman-Keuls

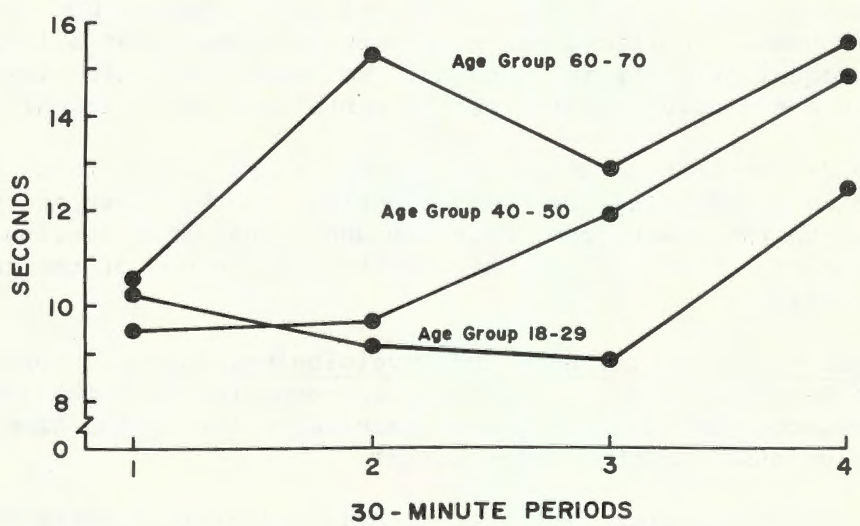

Figure 1. Mean target detection times for the three age groups.

tests revealed that there were no significant differences between the three age groups in mean detection latency during the first 30-minute period. Comparisons of the first with subsequent periods revealed a significant increase in target detection time during the second and fourth 30-minute periods for the oldest group of Ss. For the middle-aged and youngest groups, there was no significant performance impairment until the last 30-minute period. Although Figure 1 shows an apparent improvement in the performance of the oldest group during the third measurement period, this decrease in detection time was not significantly different from the times for the two adjacent periods.

TABLE 1. Mean Number of Omission and Commission Errors for Each Age Group

Age Groups	Errors: Omission	Errors: Commission
18-29	0.27	0.53
40-50	1.07	1.33
60-70	2.47	3.13

Because of relatively low frequency of occurrence of failures to respond to critical stimuli (errors of omission) and responses to noncritical stimuli (errors of commission), errors in each of these two categories were summed for each S across all four 30-minute periods. Table 1 shows an increase in both types of error with age. Analyses of variance revealed that these differences between age groups were significant for both errors of omission, $F(2/42) = 6.12$ and errors of commission, $F(2/42) = 5.79$.

Physiological Data. Mean eye fixation durations for the three age groups are shown in Figure 2. The data reveal similar patterns of change

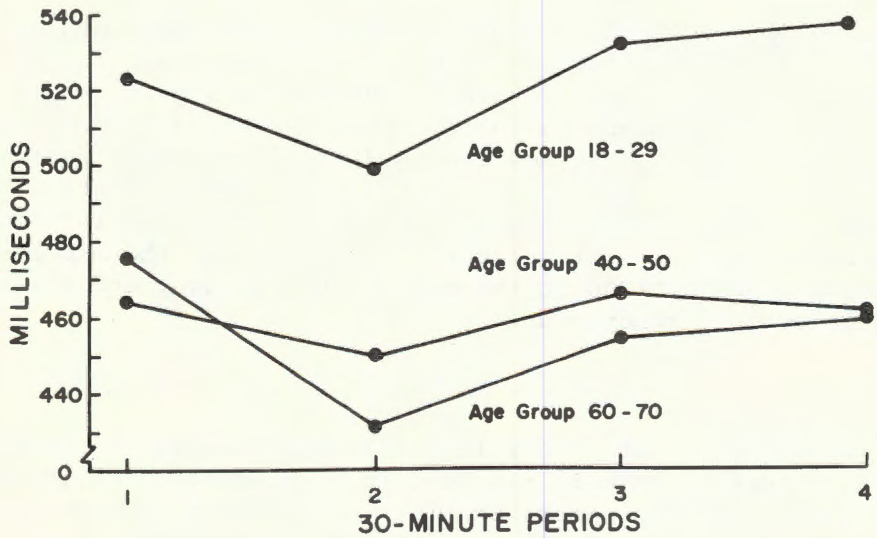

Figure 2. Mean visual fixation durations for the three age groups.

in all groups across the two-hour session and suggest differences between groups in fixation duration. Analysis of variance revealed a significant main effect for 30-minute periods ($F(3/126) = 7.50$). However, neither the difference between age groups ($F(2/42) = 2.25$) nor the age by periods interaction ($F(6/126) = 1.24$) was significant.

Mean conductance levels are shown in Table 2. Because of instrumentation problems, usable data were not available for all S's in two of the groups (this is indicated in Table 2). Consequently, an analysis of variance using an unweighted means solution was employed. Both the main effect for

TABLE 2. Mean Conductance Level (in Micromhos) at the End of Successive 30-Minute Periods for Each Age Group

Age Groups	Periods 1	2	3	4
18-29 (N=8)	9.65	8.76	8.80	7.70
40-50 (N=15)	6.46	5.89	5.56	5.29
60-70 (N=13)	4.69	3.98	3.93	3.52

age, $F(2/33) = 9.64$ and the main effect for 30-minute periods, $F(3/99) = 23.41$ were significant. There was no significant interaction. As is evident from the values displayed in Table 2, conductance level is inversely related to age and shows a general decline during the task session.

Subjective Data. Table 3 shows the mean values obtained for each of the variables contained in the rating scale administered prior to and following task performance. Analyses of variance revealed no significant differences between the age groups on any variable at the beginning of the task session. At the end of the session, the age groups differed in their ratings on only two scales. The youngest group felt itself to be less attentive than did either of the two older groups, while the oldest group remained more interested in the task than did either the youngest or the middle-aged groups. All groups were equally tired at the end of the session, and all felt the task to be "moderately monotonous."

Discussion.

The requirement to detect critical altitude changes in the presence of many similar, competing stimuli resulted in more errors of omission and commission and longer average detection times among older Ss than among younger ones. Moreover, it was found that age differences in detection time did not

TABLE 3. Mean Values Obtained for Each Rating Scale Variable for the Three Age Groups

Variable	Age Group	Mean Values with Corresponding Rating Scale Descriptors: Pre Task	Post Task	F[a]
Fatigue	18-29	4.80 (Usual level)	7.13 (More tired than usual)	-
	40-50	4.27 " "	6.93 " " " "	
	60-70	4.33 " "	6.33 " " " "	
Annoyance	18-29	1.33 (Not annoyed)	2.40 (Not annoyed)	-
	40-50	1.07 " "	1.73 " "	
	60-70	1.33 " "	1.67 " "	
Attentiveness	18-29	7.07 (Quite attentive)	3.67 (Inattentive)	6.68
	40-50	6.67 " "	5.53 (Attentive)	
	60-70	7.40 " "	5.80 (Attentive)	
Boredom	18-29	2.07 (Extremely interested)	5.87 (Indifferent)	5.15
	40-50	1.60 " "	5.27 "	
	60-70	2.00 " "	3.07 (Moderately interested)	
Monotony	18-29	-	6.33 (Moderately monotonous)	-
	40-50	-	5.93 " "	
	60-70	-	4.47 " "	

a The F values shown are for those post-task comparisons in which significant differences were obtained between age groups. There were no significant differences between groups on any pre-task measure. All comparisons were based on 2/42 df.

exist initially; they became apparent only after some period of task performance, with the oldest group showing evidence of performance impairment much earlier in the session than was the case with either of the two younger groups. This latter finding is in general agreement with the results reported by Surwillo (15) and Surwillo and Quilter (16) in their vigilance studies comparing the performance of Ss above and below 60 years of age. These results appear to suggest that age-related differences in selective attention during prolonged monitoring are time dependent, i.e., they become manifest or more pronounced only after the passage of some period of time. In the present study, both the time of occurrence and the magnitude of performance impairment were related to age.

Although most studies of selective attention have not been specifically interested in time effects (sustained attention), Farkas and Hoyer (4) did report a significant age by trials interaction with results that resembled those obtained in this study. Mean card-sorting time from the first to the fourth block of trials generally increased for their elderly group of Ss, while sorting times for the middle-aged and young groups remained the same or decreased.

In attempting to account for their significant age by trials interaction, Farkas and Hoyer speculated that fatigue and/or boredom must have been greater among the elderly Ss. The same explanation was offered by Fozard et al. (5) to account for the age-related decrement found by Surwillo and Quilter (16). In the present study, however, subjective reports following task performance revealed no evidence to indicate that the oldest Ss felt the task to be more monotonous, boring, or tiring than did the two younger groups. On the contrary, the oldest group felt less bored at the end of the session than did either the middle-aged or youngest group, and all groups felt equally tired.

Decreased visual search activity is another possible explanation for the earlier as well as greater performance decrement exhibited by the older Ss. Yet no significant differences were found between age groups in mean frequency of eye fixations or in change in frequency over time. While the electro-occulographic method employed yielded only a gross estimate of total visual scanning activity, its use in a previous study (17) revealed it to be quite reliable and to correlate highly with hand-scored measures of eye movement activity. Unfortunately, frequency of visual fixations per se provides no information with respect to the type or adequacy of the search patterns employed. Further research using more adequate techniques for assessing scanning activity would be required before it could be determined with certainity that the age-related performance differences found in this study were independent of scanning patterns.

Skin conductance level differed significantly among the age groups, but the decline in conductance over time was unrelated to age. These same findings were also reported by Surwillo (15). If it could be assumed that a lower conductance level with increasing age implied a lower arousal level, this might account for the obtained differences in performance. However, this assumption has recently been questioned by Catania, Thompson, Michalewski, and Bowman (1) who report that low conductance levels in aged Ss may be the result of a low density of active eccrine sweat glands in this age group and not necessarily an indication of lower autonomic arousal. If this is the case, then the negative correlation of conductance level with age found in the present study may be more of a manifestation of peripheral factors than a reflection of differences in arousal or activation level.

In spite of the fact that reported fatigue (tiredness) was no greater among the oldest Ss than among younger ones, the most plausible explanation for the age-related decline in performance would still seem to involve some form of fatigue process. Simple habituation concepts do not appear adequate, since numerous vigilance studies using auditory tasks, or visual tasks lacking a scanning requirement, have failed to show any age-related change in performance (3). Clearly, fatigue must be tied to the visual search requirement.

Although it is well known that visual accommodation declines with age, the possibility that this factor alone could account for age-related changes in selective attention has been largely ignored (9). Yet this factor must be taken seriously, since the decline in accommodation with age results in an increased need for visual correction, especially bifocal correction. At least one manufacturer of CRT displays has cautioned that the wearing of bifocal glasses during prolonged viewing of these displays may contribute significantly to fatigue because of the tilted head posture often required for clear vision (13). This form of fatigue may not have been adequately assessed by the subjective scales employed in the present study, and it is certainly conceivable that such fatigue could have adversely affected the search patterns of older Ss.

Research in progress will evaluate the extent to which the wearing of bifocal corrective lenses may contribute to the age-related decline in performance found in this study. Peripheral factors such as this should be carefully examined before more esoteric central processes are invoked to explain age-related changes in sustained attention during complex monitoring performance.

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