Traumatic Brain Injury, Aging and Reaction Time

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ABSTRACT: The effects of traumatic brain injury (TBI) and aging were compared on tests of simple and complex reaction time (RT). Simple RT was not significantly affected by aging or TBI. TBI patients, however, tended to be slower on Simple RT tasks, and had a larger standard deviation. Individuals over age 60 and patients of any age with TBI demonstrated slower RT with choice RT tests. In addition, both groups (those over 60 and TBI patients) were less able than other groups to inhibit the processing of redundant information. For the TBI patients, this occurred primarily on reassessment. These results suggest that the deficit in both aging and TBI is not only a generalized neuronal slowing but a more specific impairment in attentional control processes, exhibited as a deficit in focused attention.

RÉSUMÉ: Lésion cérébrale traumatique, vieillissement et temps de réaction Nous avons comparé les effets de lésions cérébrales traumatiques (LCT) et du vieillissement par des épreuves du temps de réaction (TR) simple et complexe. Le TR simple n'était pas affecté de façon significative par le vieillissement ou par une LCT. Cependant, les patients avec LCT avaient tendance à être plus lents dans les épreuves de TR simple et avaient un écart type plus considérable. Les individus au-dessus de 60 ans ainsi que les patients de tous âges avec LCT manifestaient un TR plus lent dans certaines épreuves TR. De plus, les deux groupes (les individus de plus de 60 ans et les patients) étaient moins aptes que les autres groupes à inhiber le traitement d'informations redondantes. Dans le cas des patients avec LCT, ceci survenait surtout lors de la réévaluation. Ces résultats suggèrent que le déficit dans le vieillissement et la LCT n'est pas seulement un ralentissement neuronal généralisé, mais aussi une altération plus spécifique du processus de contrôle de l'attention, manifesté par un déficit de l'attention focalisée.

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Aging and traumatic brain injury (TBI) appear to have some similar effects on complex information processing. With advancing age there is a behavioral slowing, the degree of slowing being a function of task complexity.[1-3] TBI also causes slowing of reaction time (RT).[4-6] The slowing varies with task complexity and complex choice RT best reflects the severity of TBI[7-11]. Gronwall,[12] describing the performance of patients with mild head injury, suggested that "these difficulties are similar to those a 65-year man would have if suddenly confronted with the work schedule he had coped with at 25" (p. 372).

There appear to be at least broad similarities between aging and TBI in their effect on the brain. Severe TBI results in widespread brain damage;[13-14] aging also causes diffuse loss of neurons.[15-16] Both aging and TBI may cause focal frontal lobe dysfunction. The frontal lobes are particularly sensitive to damage by the inertial effects of TBI.[13,17-20] Neuropsychological tests[21-23] and blood flow studies[24] both suggest frontal lobe dysfunction with increasing age, although these findings are not as clear cut as those for TBI.[25]

To our knowledge there has been no direct comparison of these two populations. Investigation of possible parallels is important. It would establish a rationale for longitudinal investigations of TBI individuals to see if there is acceleration of deficits with increasing age.

This paper reports the results of an experiment to compare directly the effects of TBI and aging on complex reaction time tasks. The effects of aging were evaluated by comparing three groups of subjects with ages 20-29, 40-49, and 60-69 years. The effects of TBI were evaluated by comparing 26 subjects with varying degrees of severity of closed head injury to control subjects matched for age, education and sex. We also directly compared the TBI group with the three different age groups. Simple and choice RT tasks increasing in complexity were administered. In addition, subjects were compared in their ability to ignore redundant information during a choice RT task. An inability to ignore extraneous information has been described as a specific sign of frontal lobe dysfunction.[26] We hypothesized that, compared to normal young subjects, individuals over age

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60 and patients with TBI would both (1) show a decreased speed of information processing for complex tasks, and (2) be less capable of ignoring redundant information, a deficit in focused attention.

METHODS

Study-1 — Aging

Sixty subjects (33 males, 27 females) were recruited from the community through personal contacts or through organizations such as the Seniors Employment Bureau and the Youth Employment Agency. There were 20 subjects in each of 3 groups, with each group spanning a decade. Table 1 outlines the major characteristics of the groups. All subjects had normal or corrected-to-normal vision, and no evidence of color blindness. None had a history of neurological and/or psychiatric disorders.

Study 2 — Traumatic Brain Injury

Twenty-six outpatients with varying degrees of TBI, aged 17-57 years, participated in the research. The criteria for inclusion were hospitalization for treatment of TBI, no color blindness, and a willingness to cooperate in the project. Length of time post-injury ranged from 2-144 months. Thirteen patients were tested within 12 months of injury, 8 between 12 and 36 and 5 tested more than 36 months post-injury. The severity of the TBI was characterized by the following clinical criteria: Glascow Coma Scale (GCS), duration of post-traumatic amnesia (defined as the time from injury onset to the return of memory for daily events [orientation]), coma duration, Ommaya and Gennarelli's[27] clinical classification, and the presence or absence of a focal or diffuse mass injury as defined by CT Scan. Of the 26 TBI patients, 18 were judged on a clinical basis to require a CT scan. Of these, 9 had an abnormal CT scan, of which 6 revealed a mass lesion and 3 had a focal lesion. The major clinical characteristics of the TBI patients are outlined in Table 2. Patients were matched for age (+/- 3 yrs), sex and education (+/- 2 yrs) with normal control subjects (independent from those used in study 1), none of whom had any history of neurologic and/or psychiatric disorders (see Table 1).

Tests

Apparatus

A personal computer controlled stimuli for the Reaction Time tests. Stimuli were white or colored on a constant background of dark grey and displayed on a 35cm color monitor situated 1.5 m from the subject. The approximate size for each stimulus was 5 cm square. The mean interstimulus interval was 5 s with a range from 4-6 s. Subjects pressed a button in their preferred hand for the Simple Reaction Time (SRT) tests; for the Multiple Choice Reaction Time (MCRT) tests, button responses were required by both hands.

Reaction Time Tests

1. Simple Reaction Time Test (SRT)

The subject responded as quickly as possible to the presentation of a single stimulus, randomly selected from among four designs (a circle, square, triangle or cross). All stimuli were white outlines without shading. Five practice trials were followed by 50 test trials. Mean reaction time in milliseconds was the dependent measure.

2. Multiple Choice Reaction Time Tests (MCRT)

Three MCRT tests were administered. In all conditions, stimuli were randomly presented. Stimuli were categorized as either "Target" or "Nontarget". The Target stimulus, randomly selected prior to test onset, had a 25% probability of presentation. The preferred hand was used in response to a Target, and the non-preferred hand for a Nontarget. For each MCRT test 10 practice trials were followed by 100 test trials. Mean reaction time for Target correct response trials was the dependent measure.

Easy Multiple Choice Reaction Time Test (MCRT EASY) Stimuli were four white geometric shapes: a circle, square, triangle and cross. There was no shading within the outline. One of the four was randomly selected as the Target, the remaining three being randomly presented as Nontarget.

Complex Multiple Choice Reaction Time Test (MCRT COMPLEX) Stimuli had 3 different components (shape, color, and orientation of the lines within the shape), each with four possible states: shape — circle, square, triangle or cross; color — red, blue, green or yellow; line orientation - vertical, horizontal, backward slanting (\) or forward slanting (/). The Target consisted of a randomly selected combination of these states, i.e. a red square with horizontal lines. Nontargets were all stimuli that did not possess all three of the states belonging to the Target. For example, relative to the above Target, the following would be Nontargets: a blue square with horizontal lines; a red circle with vertical lines; a yellow triangle with backward slanting lines. The probability of a specific target state (eg. red, square or horizontal lines) being in a Nontarget was 50%.

Table 1: Subject Characteristics in Study 1 and Study 2

		Age			Education			Sex		Handedness	
Group	N	Mean	Range	SD	Mean	Range	SD	M	F	R	L
Study 1											
1	20	25	20-29	3	15	11-18	2	11	9	14	6
2	20	44	40-49	3	14	5-20	4	9	11	19	1
3	20	65	60-69	3	14	10-18	2	8	12	19	1
Study 2											
TBI	26	31	17-57	12	12	7-20	3	20	6	22	4
Control	26	30	16-60	12	13	5-20	3	20	6	19	7

Table 2: Medical Variable Distribution for the 26 TBI Patients

Medical Variable	Mean	SD	Range	Distribution		
Glascow Coma Scale (at one week)	14	2	7-15	≤8 N=2	9-12 N=2	≥12 N=22
Ommaya & Gennarelli Index	3	1	1-5	≤3 N=14	>3 N=12	
Coma Duration (days)	6	16	0-75	<1 N=19	1-7 N=5	>8 N=2
Post-traumatic Amnesia (days)	20	36	0-135	<1 N=7	1-6 N=7	≥7 N=9

Redundant Multiple Choice Reaction Time Test (MCRT REDUNDANT) These stimuli appeared as complex as in the MCRT Complex condition, containing all three components. However, no state specific to the Target would ever appear in a Nontarget. For example, if the Target was a yellow cross with vertical lines, no Nontarget would be yellow, be a cross or possess vertical lines. Therefore much of the information contained in the stimuli was redundant. Subjects were clearly informed of these constraints, but they were not specifically instructed to focus on any one state. However, if the subject used this information to focus on only one stimulus state at a time (eg. the color yellow), the test reverted to the same level of difficulty as the MCRT EASY.

Procedure

Each subject was tested individually on two occasions, each testing session lasting 90 minutes. Inter-session duration was one week. Time of day was kept constant. The RT tests were presented in the order described, except that the simple RT test was administered at the end of the session as well as at the beginning. For each test the subject was told to press the button as quickly as possible without sacrificing accuracy.

Analysis

There were insufficient incorrect responses for analyses of the error reaction times. Extreme scores ("outliers"), defined as trials in which reaction times exceeded the critical value for rejection of $p \leq .01$, were removed from the sample.[28] Split-plot ANOVA's were performed on the remaining subject test scores. For the first study the ANOVA structure involved one between-group comparison of the three age-groups and two within-group comparisons of the "test" and of the "visit". For the SRT results the "test" comparison was between the SRT obtained at the beginning of the examination and that obtained at the end. For the MCRT results the "test" comparison was among the three types of MCRT (easy, complex and redundant). For the second study the ANOVA structure was the same except that the between-group comparison was between the TBI patients and the normal controls.

Results were considered significant at $p \leq 0.05$. Geisser-Greenhouse corrections were used to compensate for problems in homogeneity of the variance-covariance matrix. Post hoc comparisons were performed using the Newman-Keuls Method. In Study 1, Pearson product-moment correlations were done for age and education within each test and across the three groups. In Study 2 Pearson product-moment correlations analyzed the degree of association between the Control Group's results and their age and education. For the TBI group, correlations analyzed the degree of association between the performance and the severity indices. There were insufficient subjects for analyses according to CT scan results. Results were correlated between the first and second visits for each test, and between the first and second halves of each RT test on the first visit, to assess the reliability of the measures.

Results

Outliers and Errors

For both studies there was no statistically significant group difference between either the number of errors made or the number of outliers removed from each group. For all groups, the percentage of errors or outliers was less than 4%.

Study 1 — Aging

Simple Reaction Time Tests

There was a statistically significant Test effect of SRT [$F_{(1, 57)} = 22.72$, $p<.001$]. The RT on the second test administration was significantly slower than on the first for all groups (see Table 3).

Table 3: The Effects of Aging and TBI on Simple RT

	First Visit		Second Visit	
	Mean	SD	Mean	SD
Study 1				
Group 1 (20-29)				
SRT1	235*	28	232	26
SRT2	249	35	265	45
Group 2 (40-49)				
SRT1	232	28	225	31
SRT2	243	50	249	42
Group 3 (60-69)				
SRT1	250	30	258	54
SRT2	273	54	270	61
Study 2				
TBI				
SRT1	334	292	351	206
SRT2	357	305	409	287

* Response Time in Milliseconds.

Multiple Choice Reaction Time Tests — Target responses

Target response analysis revealed a statistically significant (Group X Test X Visit) interaction [$F_{(4, 114)} = 3.46$, $p<.01$] (see Figure 1). Post hoc analysis showed that, for all 3 groups, the Complex MCRT results were significantly slower than both the Redundant and the Easy MCRT results. However, for the eldest group (Group 3), the Redundant MCRT results were also significantly slower than the Easy MCRT results. The older subjects were not as efficient in the redundancy task. These results were consistent for both visits. Across the three groups, Group 3 reacted significantly slower than both Group 1 and Group 2 at all levels of test and visit except for the Easy MCRT in the second visit where there were no significant differences. Group 2 reaction times were somewhat slower than Group 1 results. These differences did not reach significance.

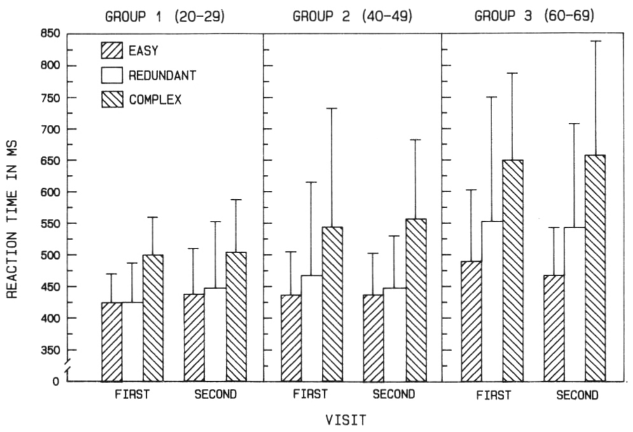

Figure 1 — Comparison of the three age groups for both the first and second visit on the three Multiple Choice RT tasks. Standard deviation bars illustrate the variance.

Correlation Analyses

Age correlated significantly with all MCRT tests except the MCRT Easy Target responses, accounting for between 11.4% and 20.5% of the total variance. Education did not correlate significantly with any of the RT measures. First to second visit correlations for all tests were significant at $p<.001$. Split-half reliability results on the MCRT tests were significant at $p<.001$.

Study 2 — Traumatic Brain Injury

Simple Reaction Time Tests

There was no significant group effect on SRT tests although the TBI group tended to react slower than the Control group (see table 3). The standard deviation in the TBI group was large. For both groups a significantly slower reaction time was observed for the second visit compared to the first [$F_{(1, 50)} = 7.7$, $p=.008$].

Multiple Choice Reaction Time Target Responses

For the MCRT tests, there was a statistically significant main effect of Group [$F_{(1, 50)} = 8.7$, $p=.005$]. Overall the TBI group reacted significantly slower than the Control group. A significant Test X Visit interaction [$F_{(2, 100)} = 24.5$, $p<.001$] confirmed that MCRT Complex results were significantly different from both the MCRT Easy and Redundant results on both visits. The second visit results were significantly slower than the first visit results for all three of the MCRT tests (see Figure 2).

Within visit subanalysis revealed a significant Group X Test interaction for the second visit ($F(2,100)=4.34$, $p<0.016$]. As above the TBI Group was significantly slower on all tests. Both groups reacted significantly slower on the MCRT Complex than on the MCRT Easy test. However, when the Easy and Redundant RT tests were directly compared, only the TBI group demonstrated significant slowing in response time for MCRT Redundant. For the TBI group, the mean difference between Redundant and Easy versions on the second visit was 66.7 ms (see figure 2). This was in contrast to the Control subjects, whose mean difference in performance between the Redundant and Easy conditions was within 10 ms.

Correlation Analyses

Neither Age nor Education correlated significantly with any of the Control group's results. The age range was limited and did not extend past age 60.

No RT measure correlated significantly with TBI severity indices. All RT measures in the TBI group were significantly correlated with Age, explaining 30-54% of the shared variance. Education unexpectedly correlated with the first administration of the SRT test, explaining 26% of the shared variance. First to second visit correlations for all RT tests were significant at $p<0.001$. All the Split-half reliability results on the MCRT tests were significant at $p<0.001$.

TBI vs Age Group Comparison

To analyze the consistency of the redundancy effect, we tabulated individual difference scores. Figure 3 presents a frequency breakdown of the number of subjects in each group in Studies 1 and 2 according to the difference in ms between Redundant RT and Easy RT. The eldest age group and the TBI groups both revealed an increased number of subjects who were slow on the Redundant RT task. Chi-square analysis revealed a significant difference between the frequency of the difference scores across three levels of age and between the TBI and control subjects (df=2, $p<.05$). When the eldest age and TBI groups were directly compared, there was no significant difference. Figure 3 also demonstrates that this slowing was variable in all groups.

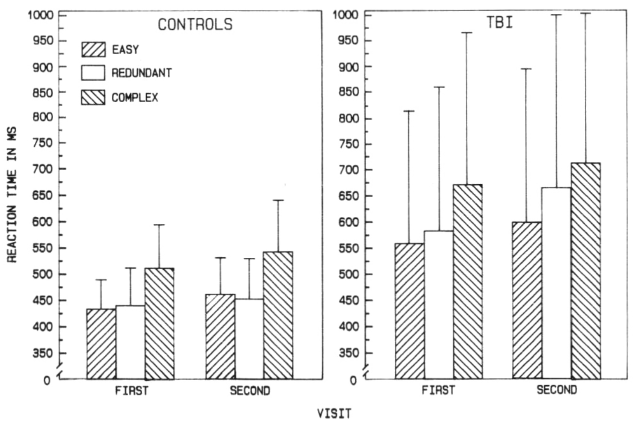

Figure 2 — Comparison of the TBI patients to their matched control subjects on the three Multiple Choice RT tasks. Standard deviation bars illustrate the variance.

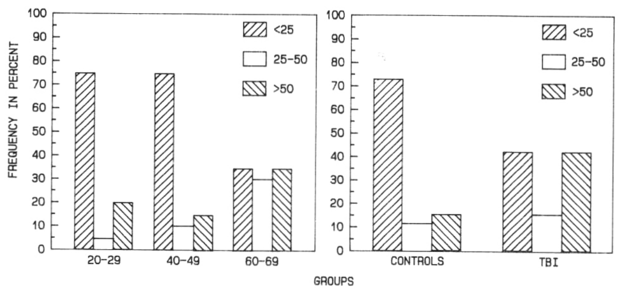

Figure 3 — Histogram of the number of subjects in each defined group based on the difference in ms between the Redundant and Easy RT tests.

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Discussion

Simple Reaction Time

There were no significant group differences for simple reaction time for either study. The literature reports little[3, 29] or no[30] change with age in simple reaction time. These results also suggest that the level of motivation was comparable across the three age groups. A significant slowing for the second simple RT task and a greater variability for the second compared to the first is probably caused by fatigue. The comparison of the TBI patients to the normal control subjects did not show any significant slowing in simple reaction time. Although the overall mean for the TBI patients was approximately 100 msec slower than the normal control subjects, the large patient variability did not result in a significant difference. This suggest that there is some change in Simple RT in at least some patients or for some trials. In summary, simple reaction time is not a sufficiently sensitive measure of the effects of either aging[30] or traumatic brain injury.[31]

Choice Reaction Time Tasks

The choice RT tests clearly demonstrated a slower RT with age and with TBI, the RT correlating with the task demands. These findings corroborate previous research.[3,29-30,32-35] Our results also replicated previous studies indicating that choice RT tests increasing in complexity revealed significantly slower reaction time in TBI patients.[9-11]

The Redundant MCRT test was designed to assess the ability of subjects to ignore extraneous information. All groups did improve on the Redundant MCRT task in comparison to the Complex MCRT task, suggesting a basic ability to focus attention. However, the TBI patients and the over age 60 subjects were less able than other groups to inhibit processing of redundant information. This effect, however, was not consistent. For example, it was observed primarily on a second visit for the TBI patients. Many subjects in the two groups did have equivalent performance on the Easy and Redundant RT tests. The correlations with the variables used in these studies do not reveal any obvious explanation for the variability. Clinically, these findings suggest that repeated assessments may be essential in uncovering specific deficits in TBI patients. Fragility in the consistent competency to focus attention may underlie certain complaints offered by these individuals, a complaint that is minimized by others because of the difficulty in objective documentation.

Similar findings have been reported in the aging literature. Older people have relatively more difficulty ignoring irrelevant information, taking a longer time to inspect the data before making a decision.[36-37] It is uncertain if this occurs due to difficulty in ignoring irrelevant information, discriminating relevant from irrelevant information, or in attending to the relevant information.[38-39] The elderly may be more rigid and may experience difficulty in overriding previously learned tasks and may tend to perseverate.[23,30,40-42] If attention is drawn to displayed elements, the elderly have difficulty ignoring the information.[43] They use or accumulate more information than necessary to make complex discriminations.[44-45]

Although in our experiment the redundant test always followed the complex, we do not believe that an inability to shift set was a factor in our experiment for the following reasons. First, the target was different for the two conditions. The subject therefore had to use a new set of criteria to detect the target in the Redundant MCRT task. Second, the redundant nontargets were detected at a speed similar to the easy nontargets. Target detection appeared to necessitate an exhaustive search, while nontarget detection depended on serial search. The elderly could reject a blue stimulus because it was not red but could not accept a red stimulus as a target until they had confirmed that it was indeed a square filled with vertical lines (even though all red stimuli were square and had vertical lines). The elderly appear to depend to a great degree on a general "confirmation bias" or positive test strategy,[46] leading to inefficient processing of target stimuli in the redundancy condition.

In the TBI literature, there is no corresponding background of similar results. A controversy has existed concerning whether a focused attention response inhibition impairment is present after TBI. These results have been inconsistent.[31,47-50] Our results suggest that TBI patients as a group are able to meet focused attention demands and may inhibit irrelevant responses to improve performance (to their own level on the easy MCRT test), as revealed by their first visit results. This "top-down", focused attention[51] is, however, completed at a cost and apparently cannot be maintained. The repeated demands of the task eventually corrodes competent performance, and the focused attention and response inhibition impairment is revealed. On the second visit the patients may decide not to or be unable to exert this amount of effort.

Based on these observations, we propose that the primary deficit in aging and TBI is not only a generalized neuronal slowing, but a more specific impairment in attentional control processes. In this regard, the inability of the elderly and the TBI patients to eliminate the processing of redundant information is similar to the known impairment of frontal lobe patients in the effective use of knowledge to regulate behavior.[26,52-55] The frontal lobes underlie the organizational and general executive control functions of behavior, including anticipation, planning, selection of goals, holding of information in memory until the goal is obtained, and the selection of means to achieve these ends. The frontal lobes are brought into play when new or complex information is processed. The processing is slower and more deliberate. Behavioral impairments as evidenced by researching patients with focal frontal lobe lesions include difficulty in selective attention, problems in using knowledge to guide behavior, difficulties in using appropriate strategies, and poor performance of the control processing, particularly when unexpected or complex information is being processed.[54-55] These functions of the frontal lobes are remarkably similar to several of the theories summarized by Salthouse[3] to explain the RT slowing with aging: strategy differences, impaired internal representation of control processes, decreased capacity of working memory, and problems in concurrent processing.

Several warnings are relevant. First, not all patients revealed these deficits. There is a heterogeneity in both aging and TBI. The results also indicate heterogeneity in "normal" subjects, a source of variability too frequently overlooked. This heterogeneity in patients and control subjects must be recognized clinically, and possible causes underlying these individual differences are yet to be fully explored. Second, although the results have suggested "frontal lobe dysfunction", pathology restricted to the frontal lobes cannot yet be concluded. A selective decrease in aging patients in blood flow in frontal and prefrontal regions has been reported,[24] but not confirmed.[25] While TBI may have a predisposition for frontal lobe damage, this is not necessary and, if present, occurs against the background of more diffuse brain dysfunction. Thus, the deficit may not be one of direct frontal lobe dysfunction but may be due to impaired transformation of information from anterior to posterior brain regions secondary to white matter disorder. Moreover, whether such problems reflect intermittent arousal deficits due to brainstem dysfunction cannot be ascertained.[56] Finally, we cannot exclude the possibility of an interactive explanation. Fatigue is relevant. Our RT tests were presented in a fixed order based on our original intention to have a build-up of redundant information. The second simple RT test was designed to control for possible fatigue effects. While there was no significant difference between the repeated simple RT tests, there was a tendency for the second test to be slower, particularly for the TBI patients. While fatigue may be a factor, however, it does not appear to be the sole explanation. It may contribute to the inconsistency of competent performance.

A parallel between aging and the effects of TBI has been proposed. Both groups have slower reactivities particularly in complex tasks and both have a deficit in focused attention as revealed in the redundancy task. These results stress the importance of a longitudinal study of TBI individuals to assess the possible interactive effect of aging with the effects of TBI.

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