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Estimation of arrival time in vehicle and video

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The equivalence of arrival-time estimations performed in vehicle and using video images was studied. The design consisted in 2 Sexes × (2 Tests × 4 Speeds × 4 Distances). The participants, 20 men and 20 women, seated in the front passenger's seat of an automobile and temporarily deprived of sight, estimated the car's arrival time at targets. The times to be estimated were generated by varying 4 speeds by 4 distances. The same subjects estimated the same arrival times in a video, filmed from the same position and scenario. Findings indicated high equivalence of vehicle and video in experimental results (underestimation of time, increase of errors with the time to be estimated). However, when considered individual skills, both estimations had a moderate relationship (*r*= .52), which, for applied purposes, does not justify substituting estimation in vehicles with that performed using videos.

Estimación del tiempo de llegada en vehículo y vídeo. Se estudia la equivalencia entre las estimaciones de tiempo de llegada realizadas en un automóvil y las realizadas en imágenes de vídeo. Los participantes, 20 hombres y 20 mujeres, sentados en el asiento del acompañante de un automóvil y privados temporalmente de visión, estiman el tiempo de llegada del automóvil a unas dianas. Los tiempos se generan variando ortogonalmente 4 velocidades y 4 distancias. Los mismos sujetos estiman los mismos tiempos de llegada en un vídeo tomado desde esa misma posición y escenario. Los resultados indican una alta equivalencia entre ambos métodos en los resultados experimentales; sin embargo, consideradas como habilidades individuales, ambas estimaciones tienen una relación moderada (*r*= .52) que para propósitos aplicados no justifica la sustitución de la estimación en automóvil por la estimación en vídeo.

Image procedures (film, video, simulation) are frequently employed to investigate time to collision or time to arrival perception in the field of driving, for experimental purposes, as well as to assess individual skills. Specifically, as regards arrival or collision time or distance estimation , few studies have been carried out using real vehicles (Aznar, Amador, Freixa and Turbany, 2000; Cavallo and Laurent, 1988; Cavallo, Laya and Laurent, 1986; Recarte and Nunes, 1998; Recarte, Nunes and Lillo, 1996; Van der Horst, 1991). Most of the reviewed works were carried out with films (Berthelon, Mestre and Nachtergaële, 1997; Berthelon, Mestre Pottier, Pons and Cavallo, 1998; Cavallo, Berthelon, Mestre and Pottier, 1998; Groeger and Comte, 1997; Manser and Hancock, 1997); however, results with these films have never been contrasted with those using real vehicles and the same subjects. Despite the extensive use of simulation to investigate arrival-time estimation, and the fact that the goal of many image tests is to substitute measurement, assessment and/or experimental research in natural situations (Aaronson and Eberhart, 1994; Garrido, Roselló, Munar and Quetgles, 2001; Gianutsos, 1994; Roselló, Munar, Justo and Arias, 1998; Watchel, 1996), there is evidence that this substitution is not always justified. Correspondence between laboratory and applied situations is far from evident because the latter introduce numerous differential aspects. Recarte et al. (1996), and Recarte and Nunes (1998), found that the correlation between arrival-time-estimation test in a real vehicle and in a 2-D simulation was zero. Nouri and Tinson (1988) found a low level of agreement (*K*= .29) between the scores obtained using a simulator and those offered by an instructor and an independent investigator on a road test, although the concordance between the two evaluators was fairly acceptable (*K*= .58). The authors concluded that measurements based on a simulator are not good predictors of driving skill. Harms (1996) found high correspondence between speed patterns in real driving and simulator driving, but not with the patterns of the lateral position in the lane. Leiser, Stern and Meyer (1991), in a simulator, found overestimation of lower speeds and underestimation of higher ones. On the other hand, Recarte and Nunes (1996), with a real vehicle, found more underestimation at the lower speeds than at the higher ones. Also, the results of Conchillo, Nunes, Ruiz and Recarte (1999) revealed these opposite patterns between the errors of estimation using video and car. In addition, the correlation between these errors (video and car) was very low, .28, but correlations of errors between the split halves were .87 in car trials , and .88 in video trials. Also, Conchillo, Hernández, Recarte and Nunes (2000); Conchillo, Hernández, Recarte and Ruiz (2000) proved that the subject behaves as a consistent estimator when he/she estimated speed inside of each other of the experimental paradigm (video or car), but this ability was not generalised from one into another paradigm. Therefore, in applied contexts such as driving it is important to know the extent to which

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both kinds of tests (real vehicles and using images) are. This applies no matter whether considering tests for evaluation, selection, drivers' licence renewal, etc., or whether it involves investigation tools in the field of vehicle driving and road safety. The general goal of this study is to establish the validity of tests using images compared with tests using real vehicles in arrival-time estimation.

Correspondence between estimations using real vehicles and using images can be established from two different viewpoints: a) in an experimental framework, based on the equivalence of mean results obtained with both procedures by manipulating the experimental variables; b) In an individual differences or correlational framework, where estimations are considered individual skills. Both outlooks are necessary because they may be irreducible, for each one analyses a component of the variance independently from the other outlook. In fact, there may be important mean differences and, nonetheless, the correlation may be very high, insofar as subjects scoring high/low in one test may also score high/low in the other. The opposite may also occur: we may obtain the same experimental effects using film as using real vehicles, and, nonetheless, the two estimation methods may not be considered the same skill because subjects' performance in one test has little or no relation to performance in the other. Therefore, if arrival-time estimations are considered a possible skill test, mere approximate correspondence of mean experimental values is not sufficient to expand results obtained using images to include real vehicle situations. In order to show the functional equivalence of both procedures, understood as skill tests, they must be performed by the same subjects and analysed as skills, using methods of individual differences, and prove that subjects who are more/less precise estimating with real vehicles should also be more/less precise using simulation or images. The arrival-time estimation results with real vehicles in Recarte et al. (1996) can be considered typical, as far as the sample (*n*= 60) and the range of speed and distances employed are concerned, and because they were replicated with other subjects and speeds (Recarte and Nunes, 1998). We present the results of this experiment below because the current experiment was based on this: 1) Subjects underestimated the vehicle's arrival time by approximately 25%; 2) the relation between real and estimated time was linear, with a slope of 0.90, indicating that errors increase slightly with the time to be estimated; 3) the fit between the increase in real time and the increase in the estimated time improved when the real time variation was caused by varying speed instead of distance. In other words, in the psychological or estimated times, speed accounted for more difference than distance, when comparing the proportion of real time differences that these two variables account for; 4) women underestimated time more than men did; 5) subjects with driving experience, especially if they had little experience, underestimated more than did subjects with no experience; 6) vision-time did not influence estimation precision, at least not when it was over 2 seconds; 7) greater or lesser estimation precision is a reliable individual skill. The current experiment employs the same procedure, materials, and variables as the reviewed one, with other subjects; these same subjects, besides estimating time in a vehicle, estimated it in videos, filmed in the same scenario as the real test. In both cases, relations were studied from the viewpoint of the way in which results were affected by experimental manipulations, as well as from the outlook of individual differences or skills. Our ultimate goal is practical: to see whether tests using videos can substitute tests using real vehicles for experimental purposes as well as for measuring skills.

Method

Participants

Forty people, 20 of each sex, ages between 20 and 30 years old (minimum age 21 and maximum 29), mean age 23.5 years and standard deviation 2.5, participated in the experiment. The groups were equalled in age (23.5 for men, 23.6 for women), in number of years participants had had a driver's licence (2.9 for men, 2.7 for women), and in driving experience (mean of 24,355 km and 27,101 km for men and women, respectively). Most of the subjects were psychology students from the last courses. They were paid for participating in the experiment.

Design

The experiment was made up of two totally comparable tests, as far as design is concerned: the real vehicle test and the video-image test. They are therefore treated as one experiment, the tests being two qualitatively different values of the variable *Test*. Test is more like a classification variable than an experimental variable, because it is practically impossible to causally attribute any significant difference between the two tests to just one aspect.

In Test 1 —arrival-time estimation in a real vehicle—, the participant, seated in the front passenger's seat of the experimental car, was deprived of vision for a variable distance from some posts situated at the end of a straight course. The participant was required to estimate the moment when the car would pass between the posts. The variables, values, and experimental conditions of arrival-time estimation of this test are the same as those in Recarte et al. (1996). Four speeds (60, 80, 100, and 120 kph) were used, orthogonally crossed with four distances (75, 100, 125, and 150 m), thus generating 16 experimental conditions. However, with regard to time, there were 13 different times instead of 16, because the 4 times along the diagonal of the Speeds x Distances matrix are the same (4.5 seconds). These 13 times varied from 2.25 to 9 seconds. As each subject performed 16 trials, the internal design of this test was 4 Speeds × 4 Distances × 2 Sexes, with repeated measurements in the 16 experimental conditions. Distance and speed values were chosen so that each variable accounted for 50% of the variance of the real times.

Test 2 —arrival-time estimation using video images— was carried out using a recording of a real-vehicle session, with a video camera placed in the subject's seat in the vehicle. Therefore, except for the reduction of the visual-field amplitude in the periphery, the camera recorded the same scene as that observed by the subject. Thus, it consisted of the same scenario, the same targets, the same course disposition, the same speeds, distances, and vision and non-vision times as in the real test.

As each subject performed both tests and experienced all the conditions within each test, the whole experiment can be described briefly as a design of 2 Tests (real vehicle, video) × 4 Speeds (60, 80, 100, 120 kph) × 4 Distances (75, 100, 125 and 150 m) × 2 Sexes, with repeated measures in the 32 conditions resulting from crossing the three experimental variables. Speed and distance were included as experimental variables to evaluate their relative contribution to time estimation in image systems. Taking into account that the same subjects performed both tests and the similarity of the tests, one could expect not only the usual generic effects that occur when a test is first or last of a sequence (attention, interest, tiredness, etc.), but probably specific effects as well, because both tests consist of the same task applied to the same situation. To control these effects, the performance order of vehicle and video tests was alternated, not only across subjects, but also within each subgroup of sex. The order of the 16 conditions resulting from crossing speed and distance within each test was varied so that the different values of the variables (speed, distance) would appear the same number of times in the various trial sequences of each test.

Materials and procedure

Test with real vehicle was carried out in the straight lane of 400 m. in a circuit 25 kms. from Madrid, with a Citröen BX 19 GTI car, equipped with recording systems. On this section, a 10-m wide and 225-m long lane was marked, using six pairs of posts, at the end of which two targets were placed. The posts were situated at distances of 225, 150, 125, 100, 75 and zero meters from the targets. The posts played a twofold role: a) to control the moments of subjects' vision and non-vision, and b) to allow measuring the time from the moment the subjects were deprived of sight until they responded that they estimated that the vehicle was passing between the targets, and also until the vehicle actually passed between the targets. A pair of posts before the six above-mentioned posts deprived the subject of vision before entering the straight lane. Each pair of posts was fitted with an infrared-emitter in the left post, and an infrared-receiver and an ultrasonic-emitter in the right post. When the vehicle passed between the two posts, the infrared beam was interrupted, so that the right post emitted an ultrasonic signal that was captured by an ultrasonic-receiver installed in the vehicle. The signal from this receiver was used for the various experimental events and recordings. The targets were two yellow-green 1.50 m × 1.50 m pieces of cloth, placed at the height of 0.5 m and separated from each other by the 10-m experimental lane. Vision control was carried out with liquid crystal glasses (Milgram, 1987), which, upon reception of an electronic signal would become translucent, and upon reception of another signal, transparent. The electronic signal was automatically activated by the signal emitted by the system of posts already described. The subject used a key-press to perform the estimation of the moment when he or she believed that the front part of the vehicle was passing between the targets; the key signal was recorded, along with the signal of the vehicle's passing between the targets. A programmable microprocessor allowed us to decide which pair of posts would deprive the subject of vision in each trial.

Before starting the test, participants were given general instructions about the task. Then, two training trials were carried out, and immediately afterwards, the 16 experimental trials, without interruption. If any trial was invalidated, it was recovered at the end of the 16 trials. Each trial included the following: a) programming the post-number corresponding to that trial, synonymous to the distance from the targets at which the subject was deprived of vision; b) Before entering the 400-m straight lane, the subject was deprived of vision by occlusion of the glasses, triggered by the signal from the first pair of posts. This was to make constant the distance at which the targets first became visible in all trials; c) In the straight lane, 225 m from the targets, the subject recovered his or her vision; this was the real start of the experimental trial; d) At a distance from the targets that was specified by the chosen post, the subject was once more deprived of vision. As of this moment, the subject's task was to press the key when he or she judged that the front part of the vehicle was passing between the two targets; e) The vehicle continued moving at the same speed and the subject remained deprived of sight until the car left the straight lane of the circuit; at this moment, subjects recovered their vision and a new trial began. The duration of this test was approximately 30 minutes.With the recorded data, we verified that the vehicle adhered to the design times, with a mean error of 7 hundredths of a second; at any rate, estimation errors were calculated with regard to the real times, not the design times.

Video test: Initial recording of the experimental videos was done without interruption while the vehicle performed the 16 trials of an ordinary experimental session, with the camera placed in the subject's seat, with a normal angular, subtending 41.28º horizontal. From this basic recording, four videos corresponding to four trial sequences were prepared by cutting the 16 trials and re-ordering them according to the sequences, so that the trials were counterbalanced as in the real vehicle. Each of the four videos was prepared and included the following elements: a) The first demonstration trial of the complete route at 70 kph; b) A second demonstration trial, same as the first, except that the image disappeared at a distance of 100 m from the targets; c) Two more demonstration trials of the complete route at 140 kph and 40 kph; d) These same two trials, reduced to 75 and 150 m, respectively, as training trials in which the subject performed his or her estimation with the key-press; e) The 16 experimental trials, in the prescheduled order. An audio signal the moment the vehicle passed between the posts (the same as the one in the circuit that deprived the subject of sight by occlusion of the glasses) was used to end the presentation of the image on the screen, which went blank. It was also the signal to the computer controlling the presentation to start measuring the time, in milliseconds, until the entry of a signal from the key-press. The video incorporated another (inaudible) audio signal corresponding to the vehicle's passage between the target posts. This signal was also transmitted to the computer, which then started a countdown of 5 seconds. This limit was chosen due to our previous experience, where no overestimation error was beyond this limit. Our aim was to make the start of a trial independent of the time the subject had taken to respond to the previous trial. The video was projected on a conventional 15-inch screen. A computer program managed instruction-presentation and the general procedure. First, self-paused instructions appeared on the screen. The scenario (half the subjects performed this test first) was described and the first example of the vehicle's course at 70 kph was presented. The instructions went on to explain that, at a certain moment of the route, the image would disappear (the same video example, but with vision cut off 100 m from the targets) and that the subject's task was to estimate the moment when the front part of the car would pass between the posts if it continued at the same speed, pressing the key. Before starting, two training scenes of the car's route were presented, at speeds and times not used in the test. Afterwards, the 16 video or simulation trials were administered without interruption, with between-trial pauses under subject control (subjects pressed a key when they were ready for the next trial).

Results

Reliability of the tests

Vehicle estimations: grouping data by speeds or by distances, the reliability mean is .80. Distance and speed displayed similar reliability in subjects' estimations (.80 and .79). Within each variable, the farther the two correlated distances (or the two speeds) are, the lower their correlation will be.

Video estimations: grouping data by distances and speeds, the reliability was 0,90 and the practical equivalence of speed and distance was also observed. The mean correlation between speeds was .90 and, when grouped by distances, it was .89.

Estimated times as a function of real times

Table 1 displays the means and standard deviations of the estimated times and errors in the two tests as a function of the real times. The standard deviations of the errors are the same as those of the estimated times. In the table, three results common to both tests are shown: (1) Arrival-time underestimation occurred and was approximately the same in both tests. (2) As the time to be estimated increased, so did the mean error. (3) As the time to be estimated increased, so did the variability of the estimations. However, we also observed three differences: The variability of the estimations was more marked in the video test than in the vehicle test. For any given time, the video test produced more variability than the real vehicle test. The consequence is that, although the means of the estimated times were better in the video than in the real vehicle test, the video-estimation correlation with the estimated times was considerably lower than the vehicle-estimation correlation. That is, a lower proportion of the variance of the video estimations was associated with the variation of the real times. This can be seen in the squared correlations in Table 2, which also displays the linear regression coefficients of the estimated times on the real times in both tests.

Table 1
Means and standard deviations (SD) of the estimated times (est.) and the estimation errors by time and test. N= 40

	Test					
	Vehicle			Video		
	Mean		SD	Mean		SD
Time	Est.	Error		Est.	Error	
2.25	1.36	0.94	0.47	1.6	0.65	0.65
2.70	1.75	1.02	0.44	1.76	0.74	0.88
3.00	1.90	1.14	0.48	2.34	0.66	0.96
3.38	2.38	1.07	0.52	2.39	0.99	1.17
3.60	2.55	1.12	0.78	3.04	0.56	1.08
3.75	2.66	1.12	0.76	3.08	0.67	1.48
4.50	3.31	1.25	0.8	3.56	0.94	1.38
5.40	4.2	1.26	1.05	3.96	1.44	1.76
5.63	4.44	1.23	1.05	4.82	0.80	1.62
6.00	4.63	1.52	0.94	4.95	1.05	1.72
6.75	5.53	1.23	1.43	5.93	0.82	2.56
7.50	6.22	1.42	1.38	6.32	1.18	2.40
9.00	7.75	1.40	1.63	7.83	1.17	2.78

Table 2
Intercept (a), slope (b), linear correlation (r) and proportion of variance accounted (r^2) for estimated times compared with real times in vehicle and video

Test	a	b	r	r^2
Vehicle	-0,88	0,95	0,87	0,76
Video	-0,52	0,92	0,71	0,50

In Table 2, it can be seen that the increase in the estimations is lower than the increase in the real times, as can be seen by the slope of the straight lines (column b in Table 2). This is because the estimation errors increased with the time to be estimated, although only slightly.

Squared, instead of linear, adjustment of the same data did not improve the correlation, and thus, the proportion of variance accounted for did not increase.

Analysis of the estimation errors as a function of the experimental variables

We performed a analysis of variance (ANOVA) of the estimation errors as a function of test (vehicle / video), distance (75, 100, 125, 150 m), speed (60, 80, 100, 120 kph), and subject's sex (two values), with repeated measures in the 32 conditions resulting from crossing the first three variables. The results revealed lack of significant effects between the tests, $F(1, 38)= 3.042$, $p>.05$; the difference between the video error (–.90) and the vehicle error (–1.21) was not statistically significant. The lack of an effect of sex, $F(1, 38)= .425$, $p>05$, was also noteworthy; nor did sex interact with any other variable.

There was a significant effect of speed, $F(3, 114)= 6.349$, $p<.001$, indicating that the higher the speed, the lower the error, going from –1.27 at 60 kph to –.88 at 120 kph.. There was no interaction between test and speed, $F(3, 114)= .740$, $p>.05$. The effect of distance was not significant, $F(3, 114)= 1.015$, $p>.05$, nor was its interaction with the test, $F(3, 114)= 1.637$, $p= .05$. There was a slight interaction between distance and speed, $F(9, 342)= 2.115$, $p<.05$, which appeared in both tests, although the interaction Distance × Speed × Test was not significant, $F(9, 342)= 1.138$, $p>.05$.

Upon analysing the errors for each test individually, the effect of speed was significant in each one: for the vehicle, $F(3, 114)= 5.76$, $p<.01$, partial $\eta^2= .132$; for the video, $F(3, 114)= 3.99$, $p<.05$, partial $\eta^2= .095$. By itself, distance did not reveal significant effects in any test considered individually: for the vehicle, $F(3, 114)= 2.01$, $p>.05$; for the video, $F(3, 114)= 0.90$, $p= .443$.

The relationship between tests

The final aim of the experiment was to establish the degree of correspondence between time estimation with real vehicle and with video, in two different ways: experimental and correlational. In this section, we shall examine the latter aspect, considering the tests as skills.

If we summarise each participant's arrival-time estimation using the mean error of the 16 vehicle trials, and we obtain a similar score for the video estimation, the global correlation between the vehicle and video estimation errors is $r = .508$ ($p<.001$). The magnitude of the relation is only moderate and does not seem sufficient to consider them functionally equivalent. Only 25.8% of the variance of the vehicle and video estimations is common, which does not seem to justify using a video test as a substitute or a predictor of the vehicle test, when considered measurements of the same individual skill.

Discussion

In the above-mentioned tests, we analysed two methods of estimating arrival time of a moving object at a specified place. One of them used a real vehicle and the other, video images. The comparison was made from two perspectives: a) from an experimental outlook, examining the equivalence of the results and the way in which they are influenced by experimental variables; b) from a correlational viewpoint, studying the equivalence of the tests as possible measurements of the same skill.

The final goal was to examine the possibility of substituting vehicle tests with image tests, which is a habitual practice in experimental research in this field and which, nevertheless, is not clearly justified. Previous results (Recarte et al., 1996) indicate that arrival-time estimation with a real vehicle and arrival-time estimation of a dot on a computer screen are not equivalent as far as experimental results and skill in arrival-time estimation are concerned. The visual mechanisms involved in processing transversal movement may be different from those concerned with frontal movement, with the vehicle.

Regarding the relations of current vehicle and video tests, the situation is complex:

On the one hand, whereas the video is acceptably parallel to the vehicle on an experimental level, they have only a moderate relationship when measuring the skill of arrival-time estimation.

From the experimental outlook, the two tests have the following main common and differentiating features:

a) In both tests, subjects underestimated arrival time, in a fairly identical fashion. This fact has often been confirmed with many variants of the basic paradigm. We believe there is no satisfactory explanation for the underestimation. Explanations based on decision criteria associated with assumed risk are inconsistent with the fact that underestimation occurs at the same rate with the vehicle and the image test.
b) Estimation variability at any given time was higher in video tests than in vehicle tests. This could mean that in the image tests, less information is available; thus, estimations do not depend so much on relevant scenario indications. On the average, this does not make estimations worse, but rather more variable, with other subject factors or characteristics, such as decision criteria, etc., intervening to a greater extent.
c) Following the same trend as point b, vehicle estimations had a higher correlation with real times than video estimations.
d) In both tests, estimation variability increased with the time to be estimated, which can be interpreted as an accumulation of uncertainty with the passing of time.
e) Video estimations were more reliable than vehicle estimations. Probably, scenario uniformity and induced mental states (in the video, a laboratory cabin; in the vehicle, a circuit, around which the car drove between trials, with distracting elements probably interfering) contributed to this result.
f) In both tests, the distance to be estimated was an important component of trial similarity: the more similar the trial distance, the higher the trials correlated. With regard to speed, this only occurred with the vehicle. Psychological similarity of tests is not based on the uniformity of the time to be estimated.
g) In both tests, estimation errors increased when the time to be estimated increased. But the slight increase of error with time only occurred when the time increment was due to speed increment, and not to distance increment.
h) With real vehicle, speed and distance accounted for the same proportion of the differences in the estimations (the same as in real times); whereas in the video, speed accounted for a higher proportion of the differences than did distance.
i) Differences in estimations associated with the subjects' sex or driving experience failed to occur in either of the two tests. In Recarte and Nunes (1998), there was a small but significant effect of sex (women underestimated more than men), which is in accordance with other results reported in literature, although this was not observed in Recarte et al. (1996). When it appears, this effect may be due to contamination by variables such as driving experience.

At the theoretical level, our results suggest two hypotheses:

The first is that arrival-time estimation does not seem to be such a primitive and invariant process as suggested by Lee (1976) in the optical flow theory. Reliability data, along with speed and distance slopes and the small influence of time itself, indicate that different signals are employed to perform estimation and that such signals vary from one trial to the next. Relationships between the trials of the two tests also indicate that the task is susceptible to being performed in different ways and that the signals and strategies employed vary from test to test.

The second is that psychological distance, speed, and time play various roles in the various tests and their relationships are also different from those in the physical world. Contrary to the physical world, time is not, psychologically speaking, a representation that is completely determinable by distance and speed. For the same physical times and the same quality of estimations, the effects and relative participation of distance and speed are quite different in the various tests.

On a practical level, the essential issue is whether image tests can substitute vehicle tests in experimental research, as well as when considered measurements of the skill of arrival-time estimation. If certain precautions are taken when interpreting results, the video can be used as an alternative to experimentation of arrival-time with vehicle. The precautions refer mainly to the fact that results may vary depending on whether the times to be estimated are generated by changing speed or distance. Videos may even have advantages over vehicles, such as greater reliability and trial uniformity. As a measurement of individual skills, however, we do not recommend the use of videos as a substitute for the vehicle test, at least, not if a decision affecting the person were to depend on such a measurement.

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