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FIAT 500L REAR IMPACT PERFORMANCE IN EURO NCAP AND IIHS ASSESSMENTS

ABSTRACT: This paper examines Fiat 500L rear-impact performance by combining published Euro NCAP and IIHS assessments with video-based kinematic reanalysis of official Euro NCAP footage. Euro NCAP reported 2.3 points and marginal whiplash protection for the 2012 European variant, whereas IIHS rated the seat and head restraint of the United States model range as good. The ratings are not directly interchangeable because the programmes used different pulses, seat specifications, measured quantities and scoring rules. To supplement the published results, WhiplashApp was used as the motion-analysis tool. Two user-defined head-region points were tracked by Lucas-Kanade optical flow, and the smoothed trajectories were used to calculate angle of head, angular velocity and angular acceleration. The resulting curves identify motion reversal, extension-rebound and intervals of rapid head rotation. These observations complement the IIHS values for favourable restraint geometry and 56 ms head contact and help explain how a good IIHS rating can coexist with the marginal Euro NCAP result. The study demonstrates the value of traceable video kinematics for interpreting published automotive test results. WhiplashApp provides an effective tool for this workflow and a suitable basis for further whiplash and video-based biomechanical analyses with additional synchronised measurement channels.

KEYWORDS: whiplash, rear impact, motion analysis, seat, head restraint, Fiat 500L

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FIAT 500L U EURO NCAP I IIHS PROCENAMA UDARA OTPOZADI

REZIME: U ovom radu analiziraju se performanse automobila Fiat 500L pri udaru otpozadi povezivanjem objavljenih rezultata Euro NCAP i IIHS ispitivanja sa naknadnom video-kinematičkom analizom zvaničnog snimka Euro NCAP testa. Euro NCAP je za evropsku varijantu vozila iz 2012. godine dodelio 2,3 poena i ocenio zaštitu od trzajne povrede vrata kao marginalnu, dok je IIHS sedište i naslon za glavu američke verzije modela ocenio kao dobre. Ove ocene nisu neposredno uporedive jer su u programima primenjeni različiti impulsi udara, specifikacije sedišta, merene veličine i pravila ocenjivanja. Kao dopuna objavljenim rezultatima, WhiplashApp je korišćen kao alat za analizu kretanja. Dve korisnički definisane tačke u oblasti glave praćene su primenom Lucas–Kanade metode optičkog toka, a izglađene putanje korišćene su za izračunavanje ugla glave, ugaone brzine i ugaonog ubrzanja. Dobijene krive omogućavaju identifikovanje promene smera kretanja, faze ekstenzije i povratnog kretanja, kao i vremenskih intervala brze rotacije glave. Ova zapažanja dopunjuju rezultate IIHS ispitivanja, koji ukazuju na povoljnu geometriju sistema za oslanjanje glave i ostvarivanje kontakta glave sa naslonom nakon 56 ms, i pomažu u objašnjenju kako dobra IIHS ocena može postojati istovremeno sa marginalnim rezultatom Euro NCAP ispitivanja. Istraživanje pokazuje značaj sledljive video-kinematičke analize za tumačenje objavljenih rezultata ispitivanja bezbednosti automobila. WhiplashApp predstavlja efikasan alat za ovakav postupak i odgovarajuću osnovu za dalji razvoj analiza trzajnih povreda vrata i drugih biomehaničkih ispitivanja zasnovanih na video-snimcima, uz mogućnost uključivanja dodatnih sinhronizovanih mernih kanala.

KLJUČNE REČI: trzajna povreda vrata, udar otpozadi, analiza kretanja, sedište, naslon za glavu, Fiat 500L

INTRODUCTION

Whiplash-associated disorders are commonly linked to low- and moderate-severity rear impacts. During the initial phase of such an event, the seat accelerates the torso while the head tends to remain behind because of inertia. The resulting relative motion depends on head-restraint geometry, seatback stiffness, energy absorption and the timing of head contact. Consumer assessment programmes therefore evaluate the seat and head restraint as a system rather than considering only the nominal presence of a restraint (IIHS, 2023).

The Fiat 500L provides an informative case because it was manufactured at the Kragujevac plant (Government of Serbia, 2012) and was assessed on both sides of the Atlantic. Euro NCAP awarded the vehicle five stars in 2012 and 94% for adult occupant protection but described its rear-impact whiplash protection as marginal. IIHS later assigned a good rating to the head restraints and seats of the United States model range. Reading these labels without the corresponding protocols could suggest a contradiction that is not supported by the available evidence.
The objective of this study is to establish which parts of the two assessments are comparable, quantify the published Fiat 500L results and identify the information required for a defensible experimental reanalysis. The study is a documentary case analysis; no unpublished manufacturer data or new sled tests are presented.

MATERIALS AND METHOD

The Euro NCAP record concerns a left-hand-drive Fiat 500L 1.4 petrol Easy 4x2, publication year 2012 and test mass 1245 kg. The published adult-occupant score was 34 points (94%), including 2.3 points for rear impact whiplash protection. Euro NCAP explicitly characterised the protection provided by the seat and head restraint as marginal (Euro NCAP, 2012a). The IIHS record identifies a manual cloth seat and states that the rating applies to 2014-2020 models. IIHS reports a good overall evaluation, good dynamic rating and good seat/head-restraint geometry (IIHS, n.d.-a).

The comparison was made at three levels: test object and occupant surrogate; excitation and positioning; and reported outputs. A value was treated as directly comparable only when its definition and unit were common to both sources. Programme-specific categories were compared qualitatively and were not converted to an artificial common numerical scale.

The Euro NCAP procedure current around the assessment period was based on three sled tests intended to represent the range of pulse shapes and velocity changes observed in rear crashes. The 2008 protocol specified low and medium pulses near 16 km/h and a high pulse near 24 km/h. Although the low and medium velocity changes were similar, their durations and acceleration-time histories differed. Thus, pulse severity cannot be described by

velocity change or peak acceleration alone. The seat was installed in a vehicle-representative geometry and loaded by a belted BioRID dummy (Euro NCAP, 2008).

Table 1 Crosswalk of the historical rear-impact assessment procedures

Characteristic	Euro NCAP procedure	IIHS procedure
Test object	Forward-facing front seat and head restraint mounted on a sled	Front seat and head restraint mounted on a sled
Occupant surrogate	BioRID rear-impact dummy, standardised seating and three-point belt	BioRID dummy with realistic articulated spine
Dynamic excitation	Three pulses: low, medium and high severity	One pulse with Δv about 16 km/h (10 mph)
Euro NCAP low	Δv 16.10 ± 0.80 km/h; 105.8 ± 3.0 ms; mean 42.35 ± 4.50 m/s²	Not applicable
Euro NCAP medium	Δv 15.65 ± 0.80 km/h; 91.0 ± 3.0 ms; mean 47.85 ± 4.00 m/s²	Closest in Δv, but not necessarily identical in shape
Euro NCAP high	Δv 24.45 ± 1.20 km/h; 107.7 ± 3.0 ms; mean 63.15 ± 4.85 m/s²	No corresponding pulse in the historical rating
Geometry	Included in protocol and assessment rules	Separate static height and backset assessment
Output	Points contributing to adult-occupant/star rating	Good, Acceptable, Marginal or Poor category

The historical IIHS evaluation used a two-stage logic. Static measurements first described the height and backset of the restraint relative to a 50th-percentile male reference. A dynamic sled test with BioRID then evaluated how the system managed occupant motion and crash energy. The dynamic pulse represented a velocity change of 10 mph, equivalent to a stationary vehicle being struck at 20 mph by a vehicle of equal mass (IIHS, 2023). This is close to the Euro NCAP medium pulse in velocity change, but equivalence of the complete acceleration histories and scoring thresholds should not be assumed.

BIOMECHANICAL AND KINEMATIC PARAMETERS

Euro NCAP assessment quantities

The Euro NCAP whiplash assessment combines complementary quantities because no single measurement fully describes the loading mechanism. The Neck Injury Criterion (NIC) represents the effect of relative horizontal acceleration and velocity between the head and the first thoracic vertebra. Nkm combines upper neck shear force and sagittal bending moment using normalising intercepts and therefore describes coupled force-moment loading. Head rebound velocity characterises forward head motion after seat and head-restraint interaction. These quantities are supplemented by upper-neck shear force, upper-neck tension, T1 acceleration and the time of head-restraint contact.

In the contemporaneous Euro NCAP adult-occupant assessment, each pulse could contribute up to three points. NIC, Nkm, rebound velocity, neck shear and neck tension each contributed up to 0.5 points, while a further 0.5 points was based on the better result from T1 acceleration or head-restraint contact time. Exceeding a capping limit in a principal criterion could reduce the complete pulse score to zero. The high-severity pulse also included a seatback-opening check, with a penalty for rotation of 32 degrees or more. Static geometry and worst-case geometry were then combined with the dynamic scores and scaled to the four-point whiplash contribution (Euro NCAP, 2013).

IIHS assessment quantities

The historical IIHS procedure divided the dynamic information into seat-design and dummy-response parameters. Time to head-restraint contact tested whether initially favourable geometry remained effective during deformation, while T1 acceleration reflected the ability of the seat to absorb crash energy and limit torso acceleration. Neck shear and neck tension were used to verify that early contact or energy absorption did not introduce unfavourable direct loading. A good dynamic rating required at least one seat design parameter to pass together with low neck forces (IIHS, 2020).

This difference in aggregation is important for the Fiat 500L. The IIHS values of 56 ms for head contact and 11.8 g for T1 acceleration describe two alternative seat-design paths in the IIHS rating logic. They cannot be inserted directly into the Euro NCAP score without confirming the pulse, reference time, filtering, dummy version and processing

window. Likewise, the reported IIHS shear and tension maxima do not reconstruct NIC, Nkm or rebound velocity, which require additional synchronised channels.

Whiplash software - Calculation of video-based kinematic quantities

For the video reanalysis, in-house WhiplashApp was used as a desktop motion-analysis application. The user manually selects points of interest in a video frame, after which the application tracks them through time by the Lucas-Kanade optical-flow method implemented through OpenCvSharp. The resulting trajectories are processed to calculate displacement, travelled distance, velocity, acceleration, distances between points, segment angles, angular velocity and angular acceleration, with smoothing applied to reduce tracking noise. Results are displayed as live plots on the WPF canvas and can be exported in CSV format.

In addition to video post-processing, the application integrates measurement hardware, including industrial cameras, the HBM Spider measurement system and Arduino triggers. This modular architecture supports synchronised experimental work and makes WhiplashApp applicable both to whiplash analysis and to related biomechanical and engineering test scenarios.

The official Euro NCAP recording of the 2012 Fiat 500L test was analysed in Whiplash software. Two points in the head region were tracked to obtain their image-coordinate histories and the orientation of the connecting segment, denoted as head angle A1. The same trajectories provided the input for the calculated translational and rotational quantities.

After spatial calibration, the tracked image coordinates x and y are expressed in physical units at equally spaced instants t_i, with the sampling interval Δt equal to the reciprocal of the verified frame rate. For an interior sample, translational velocity and acceleration can be estimated by central finite differences:

$$v_{x,i} = (x_{i+1} - x_{i-1})/(2\Delta t), \quad v_{y,i} = (y_{i+1} - y_{i-1})/(2\Delta t) \tag{1}$$

$$a_{x,i} = (x_{i+1} - 2x_i + x_{i-1})/\Delta t^2, \quad a_{y,i} = (y_{i+1} - 2y_i + y_{i-1})/\Delta t^2 \tag{2}$$

The corresponding velocity and acceleration magnitudes are obtained from their orthogonal components:

$$v_i = \sqrt{(v_{x,i}{}^2 + v_{y,i}{}^2)}, \quad a_i = \sqrt{(a_{x,i}{}^2 + a_{y,i}{}^2)} \tag{3}$$

The software calculates the unoriented angle between tracked vectors u and v from their scalar product. Angular velocity and angular acceleration then follow from the central-difference operator.

$$\theta_i = acos[(u_i \cdot v_i)/(|u_i||v_i|)] \tag{4}$$

$$\omega_i = (\theta_{i+1} - \theta_{i-1})/(2\Delta t) \tag{5}$$

$$\alpha_i = (\theta_{i+1} - 2\theta_i + \theta_{i-1})/\Delta t^2 \tag{6}$$

Before differentiation, the tracked x and y coordinates were smoothed by a centred moving-average filter with equal weights and a radius of six frames. The filtered position at sample i was calculated as.

$$\bar{p}_i = (1/N_i)\, \Sigma\, p_{i+k}, \quad k = -r, \dots, r \tag{7}$$

Translational speed was calculated from the filtered positions by a central difference over three frames.

$$v_i = ||\bar{p}_{i+3} - \bar{p}_{i-3}||/(6\Delta t) \tag{8}$$

Evaluation started at the fourth sample and ended three samples before the final sample; a value was recorded when both symmetric neighbours were valid. The speed series was then smoothed by a one-dimensional moving average with a radius of five samples.

Equation (4) yields an unoriented angle from 0 to 180 degrees, from which angular velocity and angular acceleration were calculated.

Table 2 Relationship between assessment parameters and video-derived quantities

Parameter	Euro NCAP	Historical IIHS	Video contribution
Head-restraint geometry	Static score	Static rating	Initial height and backset if scale and view permit
Head contact time	Alternative to T1 score	Seat-design parameter	Directly observable after time synchronisation
T1 acceleration	Alternative to contact-time score	Seat-design parameter	Can be estimated; instrumentation remains reference
Neck shear and tension	Separate criteria with caps	Dummy-response parameters	Not obtainable from video alone
NIC	Scored and capped	Not a rating parameter	Needs head and T1 kinematics with controlled differentiation
Nkm	Scored and capped	Not a rating parameter	Needs upper-neck force and moment channels
Head rebound velocity	Scored and capped	Not published for 500L	Derivable from calibrated head trajectory
Seatback opening	High-pulse modifier	Not part of published 500L values	Derivable from two or more seatback targets

RESULTS

The published vehicle-specific rear-impact results are summarised in Table 2, which places the Euro NCAP score beside the available IIHS rating and measured quantities. As Table 2 shows, the IIHS geometry is favourable: the restraint is relatively close to the back of the reference head and extends close to its top. The reported head-contact time of 56 ms indicates early engagement of the restraint within the dynamic event. IIHS also published a maximum T1 acceleration of 11.8 g, maximum neck shear of 52 N and maximum neck tension of 503 N. Equivalent channel maxima for the Euro NCAP Fiat 500L tests are not included in the public vehicle datasheet; therefore, a channel-by-channel numerical comparison is not possible from the identified sources.

Table 3 Published rear-impact results for the Fiat 500L

Quantity	Euro NCAP 2012	IIHS 2014-2020 applicability
Seat identification	500L 1.4 petrol Easy, LHD	Manual cloth seat
Overall rear-impact result	2.3 points; Marginal	Good
Dynamic rating	Included in programme score	Good
Geometry rating	No Fiat-specific values published in datasheet	Good
Backset	Not published	55 mm
Distance below top of head	Not published	26 mm
Maximum T1 acceleration	Not published	11.8 g
Head contact time	Not published	56 ms
Maximum neck shear force	Not published	52 N
Maximum neck tension	Not published	503 N

Figure 1 shows the two tracked head-region trajectories and the resulting head angle in Whiplash software. The analysed sequence is taken from the official Euro NCAP recording of the 2012 Fiat 500L test (Euro NCAP, 2012b).

Head angle A1 describes head-segment orientation. Its minimum, reached approximately 0.07 s after the start of the analysed interval, identifies motion reversal; the subsequent increase describes the extension-rebound phase. This event occurs in the same time range as the IIHS head-contact result of 56 ms, although the different time origins and test configurations prevent numerical equivalence. The comparison nevertheless demonstrates that Whiplash can locate candidate contact and rebound events directly from video and provide an independent check of timing parameters used in seat and head-restraint assessment.

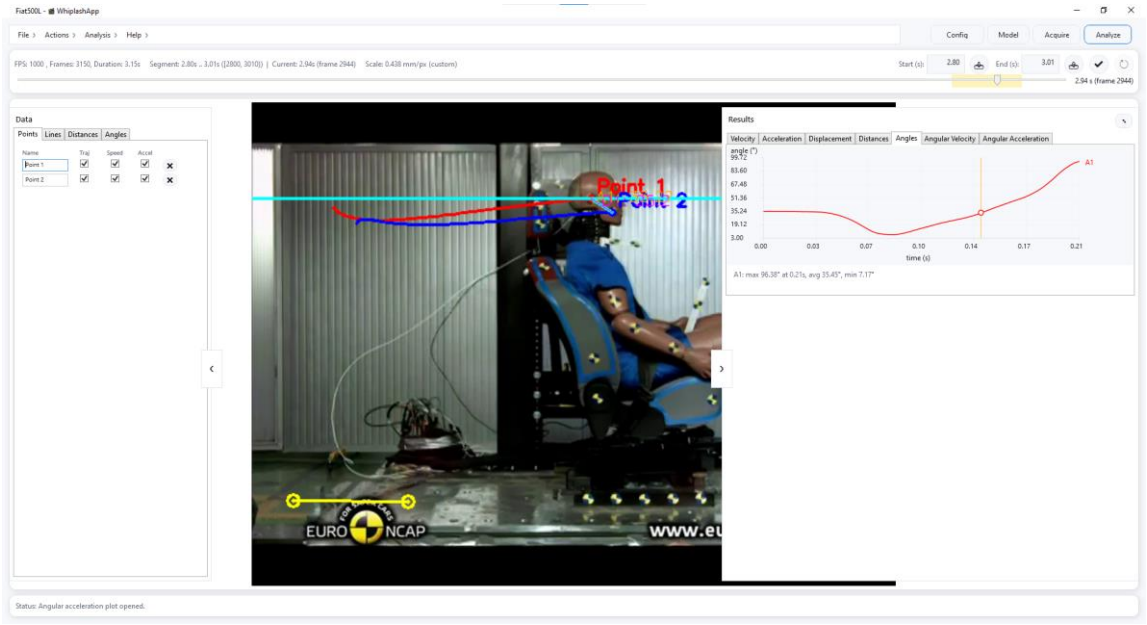
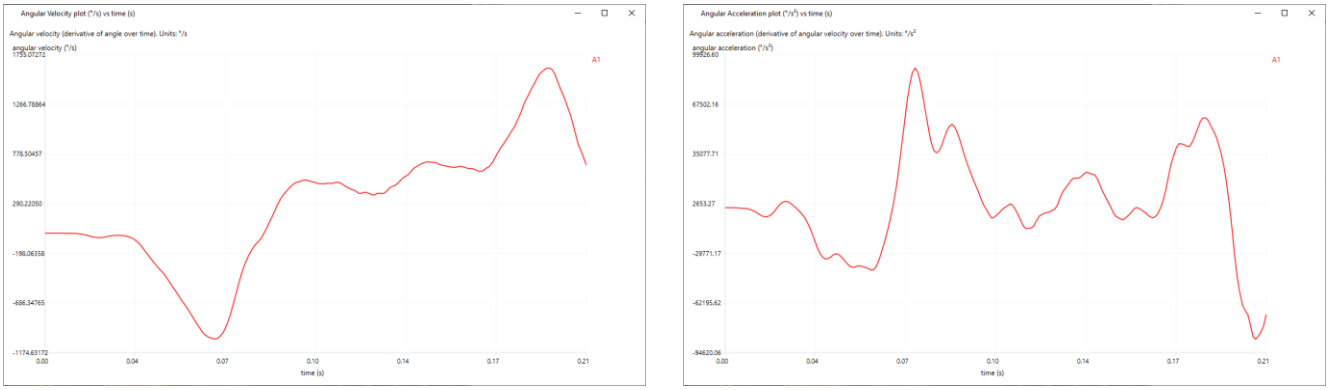


Figure 1 Fiat 500L head-point tracking and head angle in Whiplash software



(a) (b)

Figure 2 Derived rotational kinematics of head angle: (a) angular velocity and (b) angular acceleration

As shown in Figure 2, the negative angular-velocity extremum near 0.07 s and the larger positive extremum near 0.19 s separate the initial reversal from the later rebound, while angular-acceleration peaks identify the most rapid changes in rotational response. These features complement the IIHS evidence of favourable geometry and early contact by showing how the head continues to move after engagement. They are also relevant to the Euro NCAP assessment, which additionally considers rebound and neck-loading criteria over three pulses. The pronounced rotational response cannot by itself explain the marginal Euro NCAP score, but it shows why the good IIHS result and the Euro NCAP result are not contradictory. Whiplash thus supplies a traceable kinematic layer between the test video and the protocol metrics; synchronised T1 and neck-load channels would extend the same analysis to NIC and Nkm.

DISCUSSION

The difference between the published ratings is consistent with four combined factors: pulse selection, aggregation of criteria, seat specification and prescribed adjustment. Euro NCAP used three pulses, including a 24.45 km/h high-severity test, whereas IIHS combined static geometry with one approximately 16 km/h pulse. A seat can therefore achieve early contact and low forces in the IIHS configuration while showing greater rebound, seatback rotation or relative head-torso motion under another pulse. In addition, the European Easy seat and the United States manual cloth seat may differ in foam, frame, head restraint or production revision. The Whiplash curves clarify the sequence and intensity of head rotation, but the published data do not isolate which of these factors produced the different final categories.

The analysis also defines a clear route for extending the Whiplash workflow. Direct protocol comparison requires tracking the head centre, T1, head restraint, pelvis, seatback and fixed sled references. Together with synchronised sled acceleration, upper-neck forces and bending moment, these channels would enable calculation of backset, contact time, rebound, seatback opening, NIC, Nkm and the IIHS dummy-response quantities.

Planned extensions include protocol-based time-zero alignment, signed angles, automatic contact and rebound detection, video-sensor synchronisation, uncertainty evaluation, threshold comparison and automated reporting, strengthening Whiplash as a complete and auditable environment for comparative sled-test analysis.
The interpretation is subject to the limitations of the available sources. Public Euro NCAP and IIHS records do not provide complete, equivalent time histories and refer to different markets and model years. The present curves therefore support event-level interpretation, not a numerical reconstruction of either rating or inference beyond this vehicle case.

CONCLUSIONS

The Euro NCAP and historical IIHS rear-impact assessments share the same fundamental test concept: a vehicle seat is mounted on a sled and loaded by a BioRID occupant surrogate to evaluate the combined action of the seat and head restraint. Their final ratings are nevertheless not directly interchangeable. Euro NCAP used three pulses and integrated the whiplash score into adult-occupant protection, while IIHS combined static geometry with one approximately 16 km/h dynamic pulse and reported a categorical seat rating.

For the Fiat 500L, Whiplash identifies motion reversal, extension-rebound and the intervals of greatest angular velocity and acceleration in the official Euro NCAP video. These results complement the IIHS values for geometry and early head contact and help explain why a good IIHS result can coexist with the marginal Euro NCAP score of 2.3 points. These capabilities demonstrate that Whiplash is developing in a technically sound direction and provide a strong basis for further improvement. Its traceable, extensible video-processing workflow is a promising platform not only for whiplash assessment but also for other biomechanical investigations based on automotive test recordings. Additional tracked landmarks and synchronised dummy channels would enable protocol-level calculations and direct comparison with Euro NCAP and IIHS limits.

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