Calibration Test Method for enhancing the BioRID-II Dummy's Repeatability and Reproducibility

Taichi Nakajima, Kunio Yamazaki, Koshiro Ono, Yoshiji Kadotani, Masahide Sawada

Abstract The standardization of the BioRID-II has been discussed at the UN ECE/WP29/GRSP/GTR7, and setting-up this standardization has been deemed of utmost importance. One of the more important points that has been underscored is that the repeatability and reproducibility of BioRID-II when conducting sled testing, as reported by several institutes, have not been very reliable. In this study, newly proposed calibration test methods for the BioRID-II were performed. The comparison with sled test results was performed and the validity of the calibration test method was analyzed. Moreover, the calibration test method that required the dynamic responses of the dummy was also discussed. As a result, for the suggested calibration tests based on this study, the BioRID-II showed good repeatability and reproducibility. And, if the calibration test for keeping good repeatability and reproducibility is selected based on this study, the calibration test with headrest (heavy probe) will be proposed because the peak and dummy's variation occurred most notably.

Keywords BioRID-II, Calibration Test

I. INTRODUCTION

In Japan in 2008, rear-end accidents comprised around 31% of the total number (766,147) of traffic accidents. Moreover, around 90% of the injuries suffered by drivers of rear-ended cars or accidents caused by the collision of four-wheel vehicles (total number = 146,264) was minor cervical injury. Compared with other injuries, cervical injury is more likely to lead to permanent disability. Therefore, it is important to take safety measures to reduce cervical injury in traffic accidents. Currently, at the UN ECE/WP29/GRSP, an Informal Working Group on development of global technical regulation No.7 ("Head Restraint GTR Informal Meeting") has been held. Japan is joining as a technical sponsor with the current discussion focused on injury criteria and test methods etc. Various research institutes have pointed to large response variations among individual BioRID-II dummies in rear impact sled tests [1]-[4]. It is urgently necessary to reduce the response variances in order to establish a reliable test method for GTR7. Recently, a new calibration test of the BioRID-II dummy aiming to decrease the dummy's variation has been proposed. The current calibration method had various problems, for example, the path of the sled was not sufficiently linear, etc. However, these problems have been addressed in the newly proposed calibration test. In this study, the newly proposed calibration test was executed. The reproducibility of the dummies was checked using three BioRID-II dummies [5]. Moreover, from those comparisons, the validity of the calibration test method was analyzed and the items required for the calibration test were proposed.

II. METHODS

The newly proposed BioRID-II calibration test is similar to the current calibration test in that the dummy's upper body (without arms) is installed on a mini-sled which receives impacts by a pendulum. The differences between the newly proposed calibration test and the current calibration test are as follows: The mini-sled of the newly proposed calibration test slides on rails and it is heavier with its steel construction. The new sled is equipped with a new buffer material called ETD (energy transfer device) instead of the foam block attached to the current mini-sled. In addition, the adoption of the headrest is examined. The proposed calibration test will use two different types of probes according to a test with headrest or without headrest: the 37.68 kg probe

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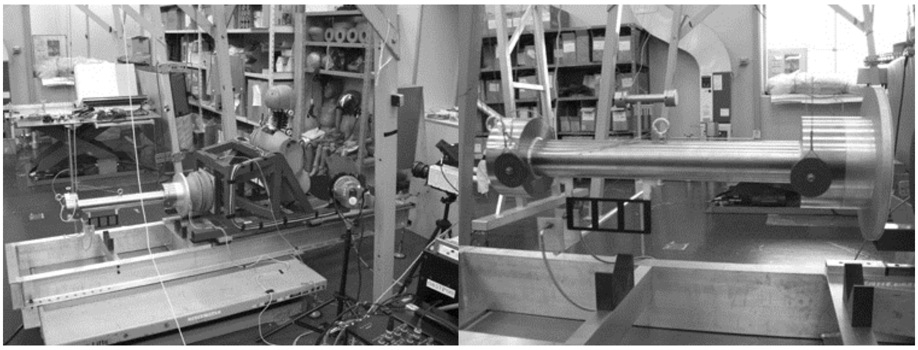
(light probe) without headrest and the 119 kg probe (heavy probe) with headrest. A list of the parameters to be recorded in the calibration is shown in Table 1. While the newly proposed calibration test with headrest will use a heavy probe, this study used both light probe and heavy probe to study the effects of differences in probe weight. Figure 1 shows the setup of the proposed calibration test without headrest, Figure 2 shows the setup of the proposed test with headrest and light probe, and Figure 3 shows the test setup with a heavy probe. Three BioRID-II version (G) dummies were used in this study to estimate reproducibility among them. Table 2 shows the detailed specifications of the test dummies.

Table.1 Measurement Item

Pendulum Velocity	m/s	UpperNeck-FX	N
Pendulum Force	N	UpperNeck-FZ	N
Sled Acceleration	m/s^2	UpperNeck-MY	Nm
Head Restraint Contact Time	ms	LowerNeck-FX	N
		LowerNeck-FZ	N
T1 Acceleration	m/s^2	LowerNeck-MY	Nm

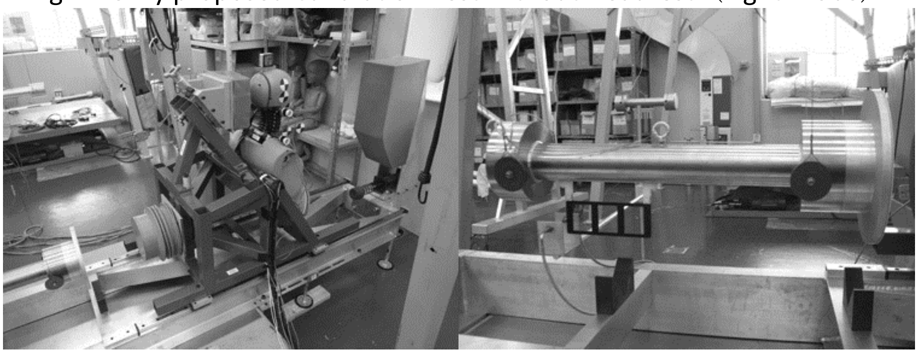
Table.2 BioRID-II version (G) Dummies

	JARI		Humanetics
Lot.No	095G	102G	115G
Neck Load Cell	No.147	No.155	No.165
T1 Load Cell	No.168	No.79	No.91
Since	2008	2009	2010



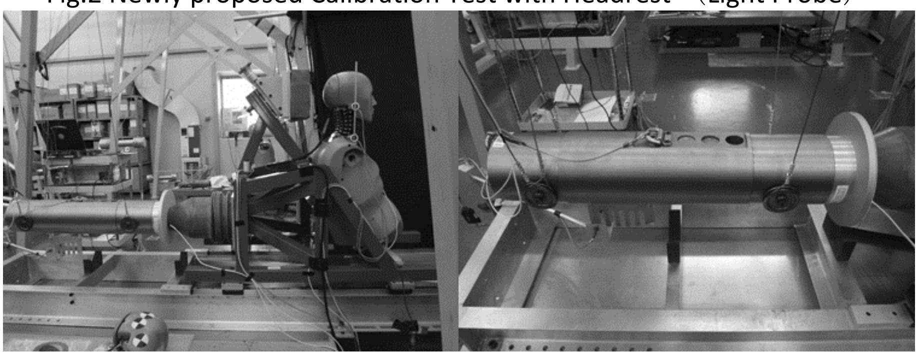
(a) Situation of Calibration Test (b) Light Probe (37.68kg)

Fig.1 Newly proposed Calibration Test without Headrest (Light Probe)



(a) Situation of Calibration Test (b) Light Probe (37.68kg)

Fig.2 Newly proposed Calibration Test with Headrest (Light Probe)



(a) Situation of Calibration Test (b) Heavy Probe (119kg)

Fig.3 Newly proposed Calibration Test with Headrest (Heavy Probe)

III. RESULTS

Calibration Test without Headrest (Light Probe)

Table 3 and Figure 4 show the results of the newly proposed calibration test without headrest; in addition, Table 3 shows the results of coefficient of variation (C.V.) and standard deviation in order to examine the reproducibility of BioRID-II dummies. Since the rebound values are not evaluated in the current calibration test, these values are not evaluated in this study. All the tests on the individual dummies recorded highly consistent values of pendulum forces with a low C.V. of 0.2%, the same load inputs among the tests on individual dummies. Sled accelerations were also consistent among the tests as indicated by a low C.V. of 0.1%. Regarding the dummies' parameters to be recorded in the calibration, phase shift in the waveform of the 095G dummy was found in the UpperNeck and LowerNeck forces and moments. However, the C.V. was below 10% for all the measured parameters to be recorded in the calibration, thus proving favorable reproducibility among BioRID-II dummies. Moreover, the C.V. was below 10% for all the measured parameters to be recorded in the calibration, confirming good repeatability of the BioRID-II dummy.

Table.3 Result of Calibration Test without Headrest (peak value)

Without Headrest	Impact Acc. (m/s^2)	SLED Acc. (m/s^2)	T1 Acc. (m/s^2)	UpperNeck FX (N)	UpperNeck FZ (N)	UpperNeck MY-Flx. (Nm)	UpperNeck MY-Ext. (Nm)	LowerNeck FX (N)	LowerNeck FZ (N)	LowerNeck MY-Flx. (Nm)	LowerNeck MY-Ext. (Nm)
095G	247.2	162.2	-233.7	171.6	332.9	13.5	-18.9	163.5	127.2	4.6	-14.0
102G	246.3	162.5	-228.1	195.6	330.5	13.8	-18.3	178.8	134.5	4.1	-15.9
115G	246.9	162.2	-247.2	199.9	321.7	13.6	-18.2	-	-	4.7	-16.8
C.V.(%)	0.2	0.1	4.2	8.1	1.8	1.1	2.2	-	-	7.2	8.9
S.D.	0.5	0.2	9.8	15.2	5.9	0.1	0.4	-	-	0.3	1.4

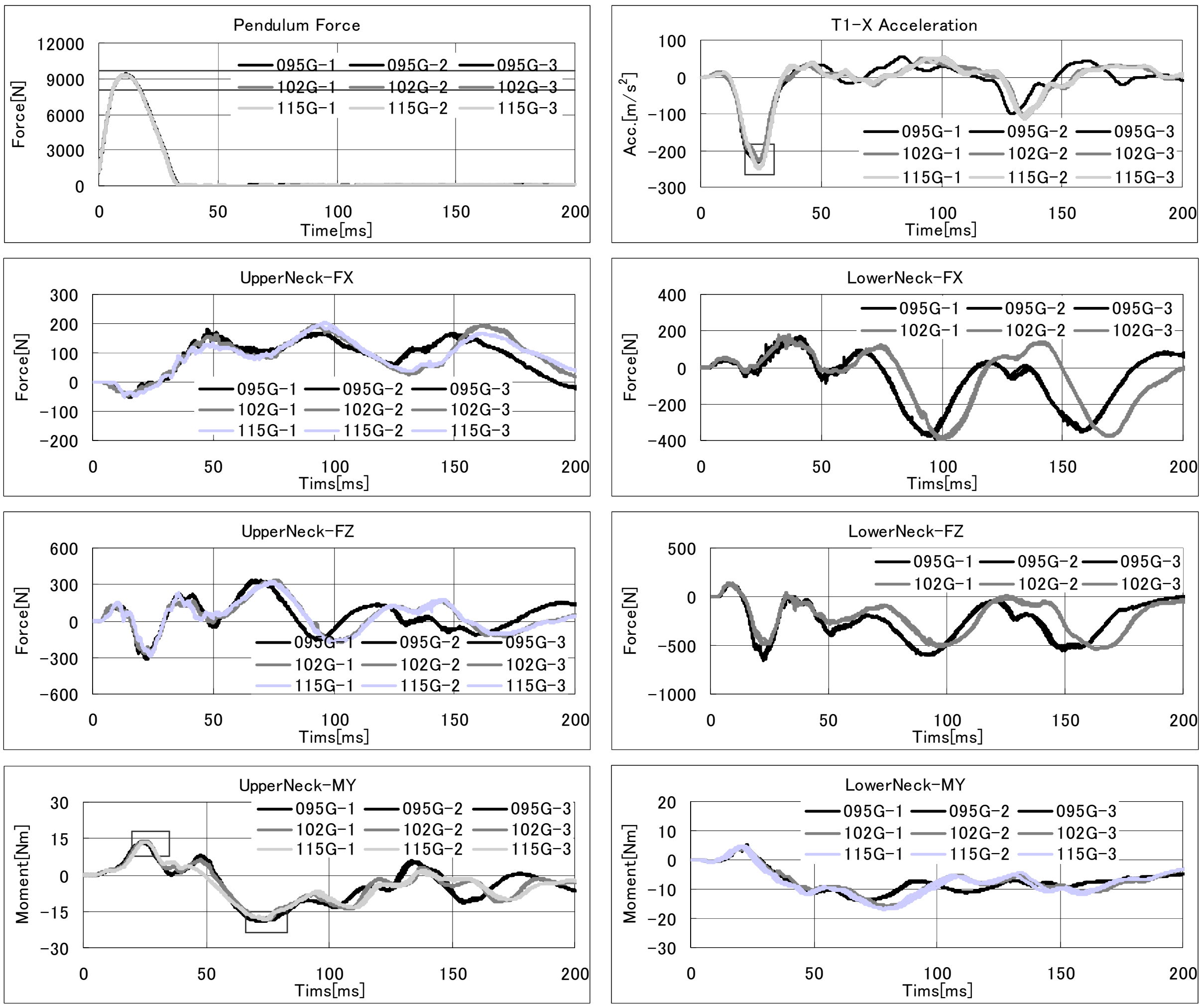


Fig.4 Result of Calibration Test without Headrest (Waveform)

Calibration Test with Headrest (Light Probe)

Table 4 and Figure 5 show the results of the newly proposed calibration test with headrest and a light probe; additionally, Table 4 shows the results of C.V. and standard deviation for examining the dummies' reproducibility. Since the rebound values are not evaluated in the current calibration test, these values are not evaluated in this study. All the tests on the individual dummies recorded highly consistent values of pendulum forces with a C.V. of 0.2%, indicating identical load inputs among the tests. Sled accelerations were also consistent as indicated by a C.V. of 0.2%. Regarding parameters to be recorded in the calibration, the only value of C.V. exceeding 10% was found in the LowerNeck-MY (Flx) where it was 18.8%. The value of C.V. of other parameters to be recorded in the calibration all recorded less than 5%, and the dummy's reproducibility was also considered to be good. Moreover, the C.V. was below 10% for all the measured parameters to be recorded in the calibration, confirming good repeatability of the BioRID-II dummy. Regarding waveforms, a phase shift was observed only in the 095G dummy from the start of headrest contact. The waveform of phase shift with the 095G dummy occurred at the newly proposed calibration test with headrest.

Table.4 Result of Calibration Test with Headrest・Light probe (peak value)

Light Probe	Impact Acc. (m/s^2)	SLED Acc. (m/s^2)	T1 Acc. (m/s^2)	UpperNeck FX (N)	UpperNeck FZ (N)	UpperNeck MY-Flx. (Nm)	UpperNeck MY-Ext. (Nm)	LowerNeck FX (N)	LowerNeck FZ (N)	LowerNeck MY-Flx. (Nm)	LowerNeck MY-Ext. (Nm)
095G	228.4	119.5	-179.9	135.3	216.4	11.1	-7.3	178.1	157.5	5.7	-12.1
102G	227.7	119.7	-172.7	129.0	219.8	13.0	-6.9	178.0	160.0	2.8	-10.8
115G	226.7	120.0	-175.3	117.2	228.2	11.6	-7.1	177.9	143.1	3.3	-11.6
C.V.(%)	0.2	0.2	1.1	3.8	1.8	4.2	1.9	1.8	3.8	18.8	3.1
S.D.	0.9	0.5	3.5	8.6	6.8	0.9	0.2	5.6	10.4	1.4	0.6

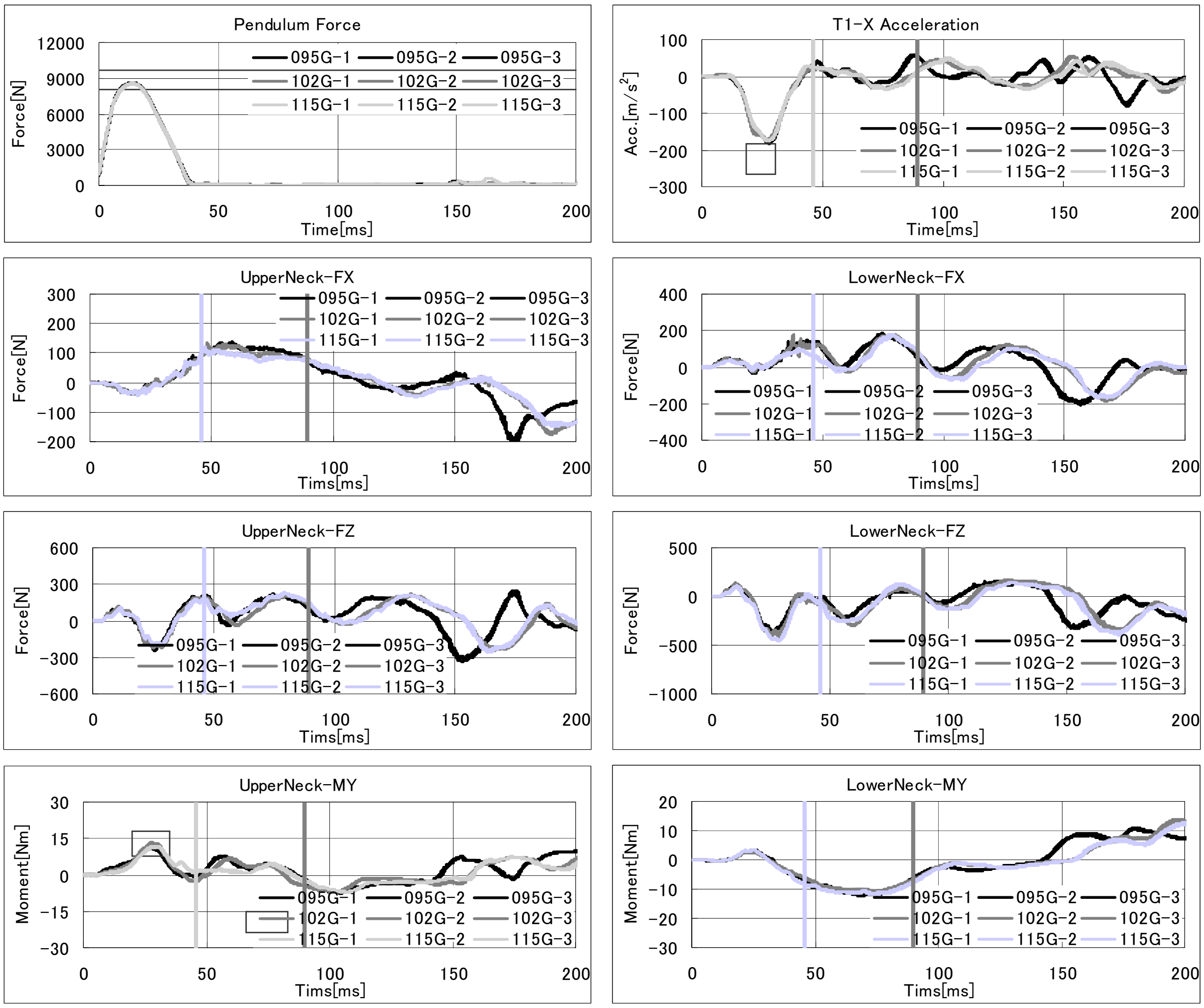


Fig.5 Result of Calibration Test with Headrest・Light Probe (Waveform)

Calibration Test with Headrest (Heavy Probe)

Table 5 and Figure 6 show the results of the newly proposed calibration test with headrest and a heavy probe; additionally, Table 5 shows the results of C.V. and standard deviation for examining the dummies' reproducibility. Since the rebound values are not evaluated in the current calibration test, these values are not evaluated in this study. All the tests on the individual dummies recorded highly consistent values of pendulum forces with a C.V. of 0.7%, indicating identical load inputs among the tests. Sled accelerations were also consistent as indicated by a C.V. of 1.0%. Regarding the parameters to be recorded in the calibration, the only value of C.V. exceeding 10% was found in the LowerNeck-FZ where the C.V. was 22.5%. The value of C.V. of other parameters to be recorded in the calibration all recorded less than 5%, and the dummy's reproducibility was also considered to be good. Moreover, the C.V. was below 10% for all the measured parameters to be recorded in the calibration, confirming good repeatability of the BioRID-II dummy. Regarding waveforms, there were no injury values that showed a phase shift, unlike the tests with a light probe.

Table.5 Result of Calibration Test with Headrest・Heavy Probe (peak value)

Heavy Probe	Impact Acc. (m/s^2)	SLED Acc. (m/s^2)	T1 Acc. (m/s^2)	UpperNeck FX (N)	UpperNeck FZ (N)	UpperNeck MY-Flx. (Nm)	UpperNeck MY-Ext. (Nm)	LowerNeck FX (N)	LowerNeck FZ (N)	LowerNeck MY-Flx. (Nm)	LowerNeck MY-Ext. (Nm)
095G	85.7	101.7	-108.9	58.4	380.7	25.4	-8.7	292.4	100.3	1.2	-12.9
102G	84.4	98.9	-116.4	49.7	378.7	23.5	-9.8	304.9	114.2	1.4	-12.7
115G	83.4	97.9	-118.7	50.8	399.7	16.8	-9.0	278.7	182.8	1.3	-14.4
C.V.(%)	0.7	1.0	2.6	5.2	1.8	9.3	3.9	2.4	22.5	9.0	3.7
S.D.	1.1	1.8	5.0	4.9	12.2	3.9	0.6	12.3	41.8	0.2	0.8

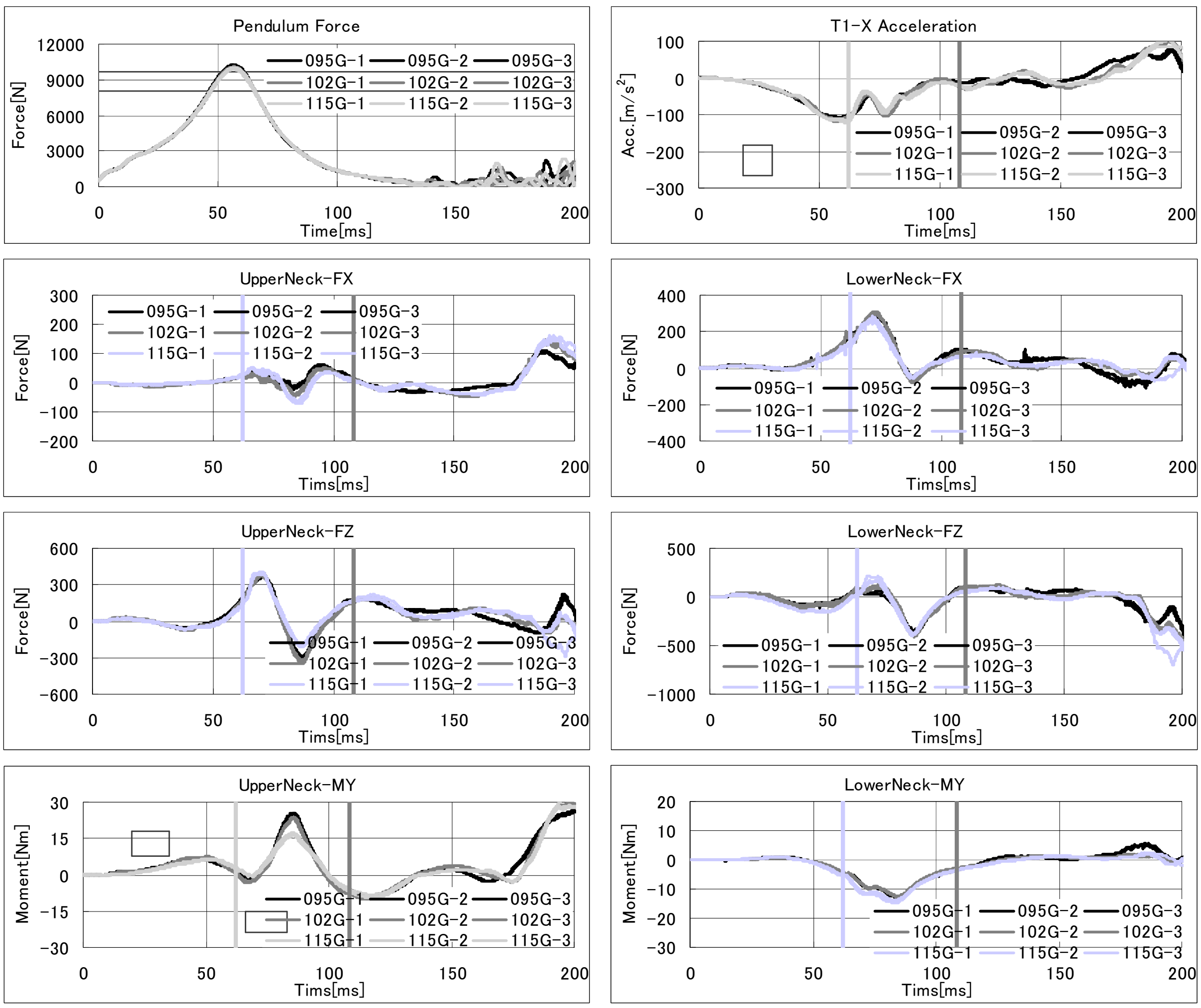
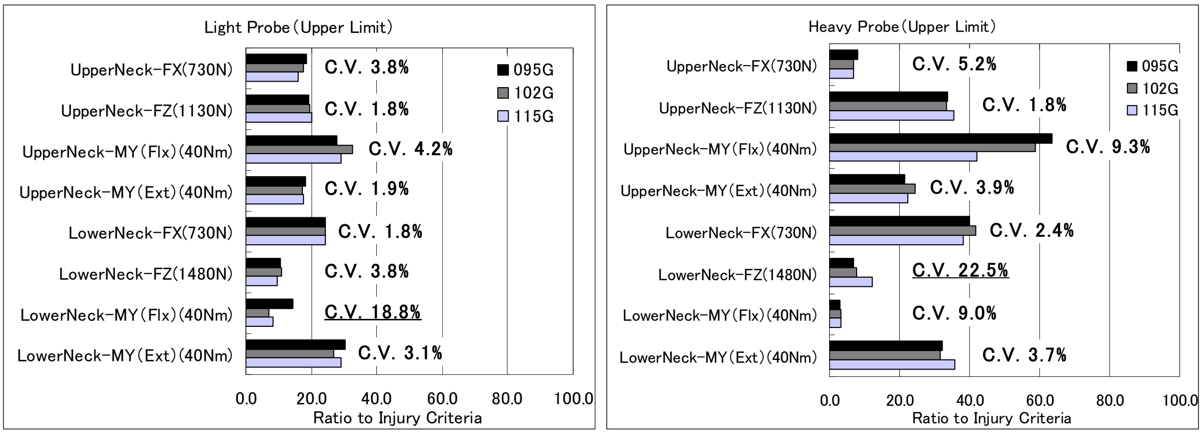


Fig.6 Result of Calibration Test with Headrest・Heavy Probe (Waveform)

IV. DISCUSSION

Confirmation of variation in the values of parameters to be recorded in the calibration where value of C.V. exceeded 10%

The values of parameters to be recorded in the calibration where the value of C.V. exceeded 10% were LowerNeck-MY (Flx) in calibration tests with headrest (light probe) and LowerNeck-FZ in calibration tests with headrest (heavy probe). In order to verify response variations among the dummies, the ratios of calibration test results to injury criteria values were calculated for comparison with the values of WAD2+Risk95%[6]-[10]. Figure 7 shows the calculated ratios for the light probe and heavy probe cases. As a result, the values of parameters to be recorded in the calibration with a C.V. that exceeded 10% indicated variations in the low parameters to be recorded in the calibration region with no more than 20% of the injury criteria values. As for the LowerNeck-MY (Flx), the test result was 2.8-5.7Nm and the criterion value was 12Nm. As for the LowerNeck-FZ, the test result was 100-182N, the criterion value was 340N and the test results were very low compared with the injury criteria value. Therefore, these variations were measurement values near the lower limit of an actual injury criteria value that has been proposed in Japan, and it can be judged as an inconsiderable range.



Light Probe Heavy Probe

Fig.7 Ratio to Injury Criteria

Verification of the phase shift of 095G dummy waveforms in the Light Probe test

In calibration tests without headrest and with headrest used with the light probe, phase shifts occurred in the 095G dummy's waveforms. To determine the causes, a verification test was conducted adopting the calibration test with headrest used with the light probe and with 095G and 102G dummies. Since the effect of jackets was suspected to influence phase shifts, the 095G dummy spine was installed in the 102G dummy's jacket (095G-Spine+102G-Jacket) and the 102G dummy spine was installed in the 095G dummy's jacket (102G-Spine+095G-Jacket) to check the effect of jackets on these calibration tests. Figure 8 shows the test results for 095G-Spine+102G-Jacket and Figure 9 shows the test results for 102G-Spine+095G-Jacket. The results of calibration tests with headrest used with the light probe are also shown in Figures 8 and 9.

The test results given in Figure 8 are summarized as follows in relation to each parameter to be recorded in the calibration.

- UpperNeck-FX: There was practically no variation in the waveform shapes of the dummies.
- UpperNeck-FZ: The results of 095G-Spine+102G-Jacket indicated a waveform phase practically identical to the waveform phase of 102G. Consequently if dummies were installed in the same jackets, there was no variation in their waveform phases.
- UpperNeck-MY: There was no significant variation in the waveforms, and 095G-Spine+102G-Jacket results were fairly near to 102G.
- LowerNeck-FX・FZ・MY: The results of 095G-Spine+102G-Jacket indicated a waveform phase practically identical to the waveform phase of 102G. Consequently if dummies were installed with the same jackets, there was no variation in their waveform phases.

Next, the test results given in Figure 9 are summarized as follows in relation to each parameter to be recorded in the calibration.

- UpperNeck-FX: There was practically no variation in the waveforms of the dummies.

- UpperNeck-FZ: The results of 102G-Spine+095G-Jacket indicated a waveform phase practically identical to the waveform phase of 095G. Consequently if dummies were installed with the same jackets, there was no variation in their waveform phases.
- UpperNeck-MY: There was no significant variation in the waveforms, and 102G-Spine+095G-Jacket results were fairly near to that of 095G.
- LowerNeck-FX・FZ・MY: The results of 102G-Spine+095G-Jacket indicated a waveform phase practically identical to the waveform phase of 095G. Consequently if dummies were installed with the same jackets, there was no variation in their waveform phases.

The test results of 095G-Spine+102G-Jacket and the test results of 102G-Spine+095G-Jacket showed little if any variation when the dummies were installed with the same jackets, therefore highlighting the interaction of the jacket and the spine. The hardness characteristic of the jacket became the focus of attention and this was measured with a hardness meter. The results were a hardness level of 6 for the 095G jacket and a level 3 for the 102G jacket. The measurement of the 115G jacket also showed a hardness level of 3. It was therefore thought that jacket hardness had an effect on waveform phase shifts, causing the test results of the 095G dummy to differ from those of the other dummies. The regulatory error range for manufacturing a dummy jacket is between a hardness of 3 and 6 which was reflected in our test results. In order to improve the repeatability of the jacket, however, there is a need to make the variation of products as small as possible. Hardness of rubber is the relative displacement of the resistance when forcing the surface with a needle that is not sharp (e.g. JIS K 6253 and ISO 7619). (Example, Human skin has a hardness level of about 10.)

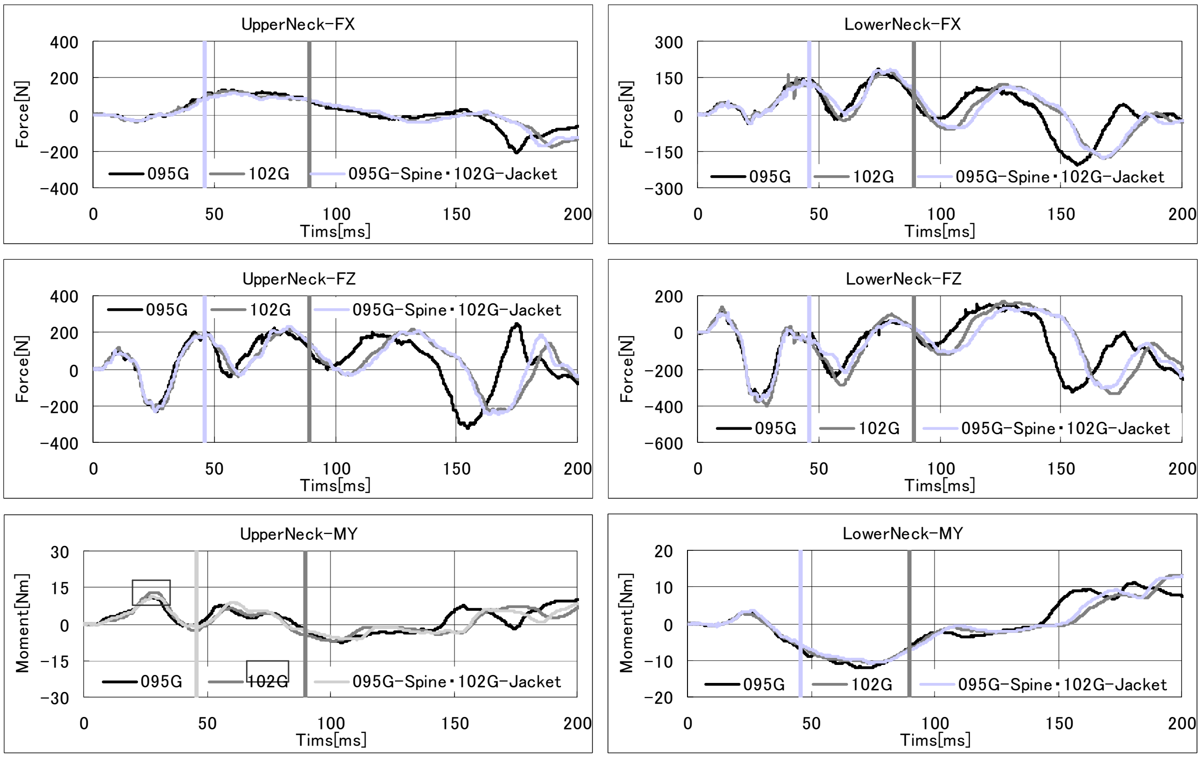


Fig.8 Result of Confirmation Test by Calibration Test (095G-Spine＋102G-Jacket)

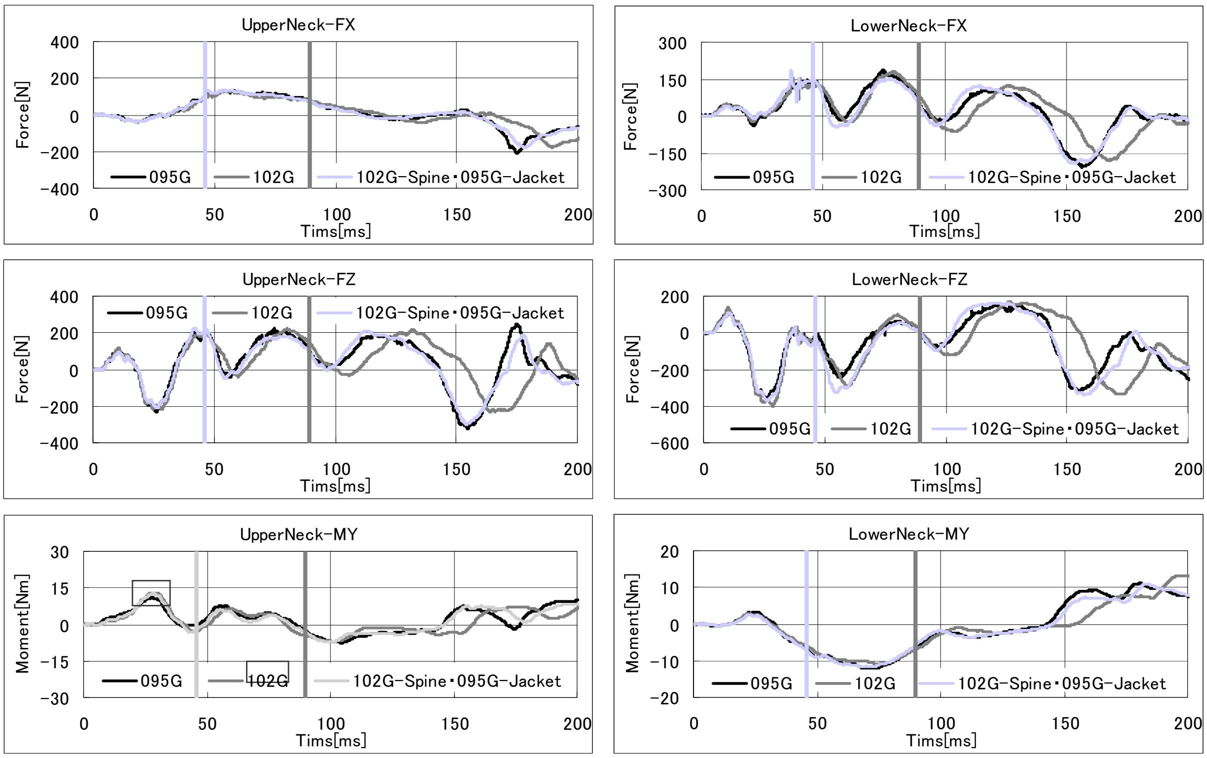


Fig.9 Result of Confirmation Test by Calibration Test (102G-Spine＋095G-Jacket)

Comparison of Calibration Test Results and Sled Test Results

The results of calibration tests without headrest and with headrest (light probe and heavy probe) were compared with earlier sled test results using a normal seat and a reactive seat as shown in Figures 10, 11, 12 and Table 6.

First, the test results given in Figure 10 are summarized as follows in relation to each of the parameters to be recorded in the calibration.

- UpperNeck-FX, FZ: The calibration test results differed from the sled test results in that there was no clear peak value, the parameters to be recorded in the calibration output were lower and the waveform shape was different.
- UpperNeck-MY: Compared to the sled tests, the calibration test results indicated a lower peak value (5Nm Flexion) and a faster peak time (100ms Flexion); the parameters to be recorded in the calibration output were lower and the waveform shape was different.
- LowerNeck-FX・FZ: The calibration test results differed from the sled test results in that there was no clear peak value, the injury value output was lower and the waveform shape was different.
- LowerNeck-MY: Compared to the sled tests, the calibration test results indicated a lower peak value (5Nm Extension) and a faster peak time (50ms Extension); the parameters to be recorded in the calibration output were lower and the waveform shape was different.

Next, the test results given in Figure 11 are summarized as follows in relation to each of the parameters to be recorded in the calibration.

- UpperNeck-FX: Compared to the sled tests, the calibration test results indicated a lower peak value (120N) and a faster peak time (90ms); the parameters to be recorded in the calibration output were lower and the waveform shape was different.
- UpperNeck-FZ: The calibration test results differed from the sled test results in that there was no clear peak value, the parameters to be recorded in the calibration output were lower and the waveform shape was different.
- UpperNeck-MY: Compared to the sled tests, the calibration test results indicated a lower peak value (8Nm Flexion) and a faster peak time (100ms Flexion); the parameters to be recorded in the calibration output were lower and the waveform shape was different.

- LowerNeck-FX・FZ: The calibration test results differed from the sled test results in that there was no clear peak value, the parameters to be recorded in the calibration output were lower and the waveform shape was different.
- LowerNeck-MY: Compared to the sled tests, the calibration test results indicated a lower peak value (10Nm Extension) and a faster peak time (50ms Extension); the parameters to be recorded in the calibration output were lower and the waveform shape was different.

Lastly the test results given in Figure 12 are summarized as follows in relation to each of the parameters to be recorded in the calibration.

- UpperNeck-FX: The calibration test results differed from the sled test results in that there was no clear peak value, the parameters to be recorded in the calibration output were lower and the waveform shape was different.
- UpperNeck-FZ: Compared to the sled tests, the calibration test results indicated a lower peak value (600N) and a faster peak time (80ms), and the parameters to be recorded in the calibration output were lower. However, the waveform shape resembled that of the sled tests.
- UpperNeck-MY: Peak values were similar between the calibration and sled tests, but the calibration test result recorded a faster peak time (50ms Flexion). However, the waveform shape resembled that of the sled tests.
- LowerNeck-FX: Compared to the sled tests, the calibration test results indicated a lower peak value (300N) and a faster peak time (70ms), and the parameters to be recorded in the calibration output were lower. However, the waveform shape resembled that of the sled tests.
- LowerNeck-FZ: The calibration test results differed from the sled test in that there was no clear peak value, the parameters to be recorded in the calibration output were lower and the waveform shape was different.
- LowerNeck-MY: Compared to the sled tests, the calibration test results indicated a lower peak value (5Nm Extension) and a faster peak time (60ms Extension), and the parameters to be recorded in the calibration output were lower. However, the waveform shape resembled that of the sled tests.

As a result, the calibration tests without headrest and that with headrest (light probe and heavy probe) recorded peak values lower than the sled tests. The calibration test with headrest and heavy probe, however, produced a waveform shape that most resembled the sled tests. Consequently the calibration method that would generate the test results (especially waveforms) similar to the sled test results was considered to be the calibration test with headrest (heavy probe). This test also recorded slightly higher peak values and variations. Therefore, if a calibration test method that reduced the dummy's variations were to be selected, it would be the calibration test with headrest (heavy probe), as it gives higher peak values and variations. However, several problems were found in the newly proposed calibration test. Though the study of the calibration test method to ensure reproducibility and repeatability for BioRID-II is important, it was thought that it was important to exclude the factors that influenced these such as the dummy seating method and test conditions (seat characteristic and seat shape, etc.).

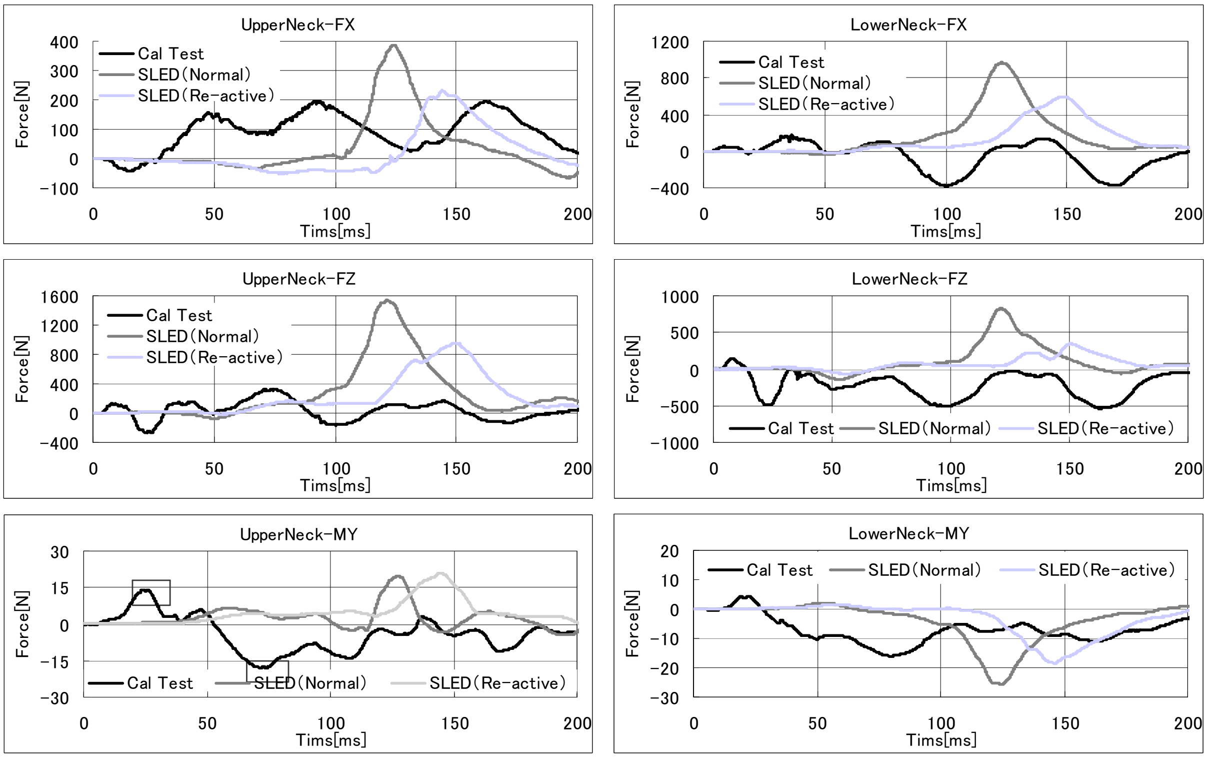


Fig.10 Comparison of Calibration Test without Headrest Results and Sled test Results

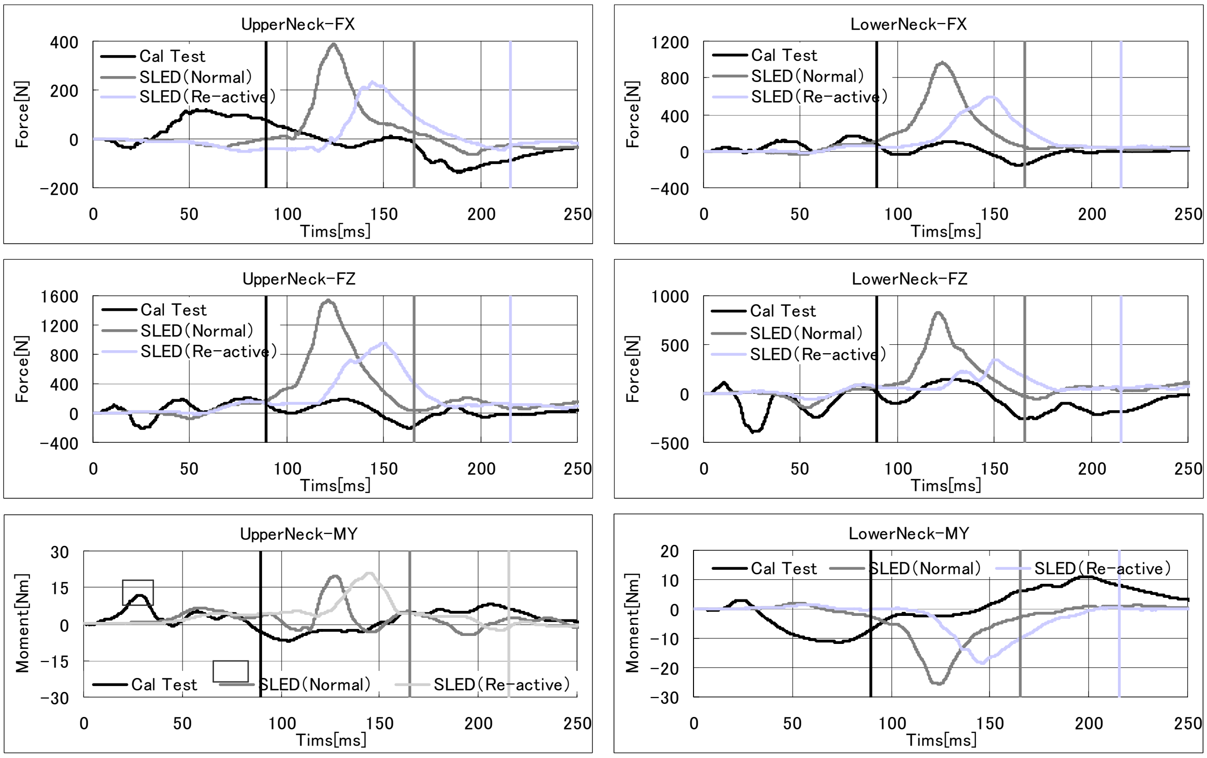


Fig.11 Comparison of Calibration Test with Headrest Results (Light Probe) and Sled test Results

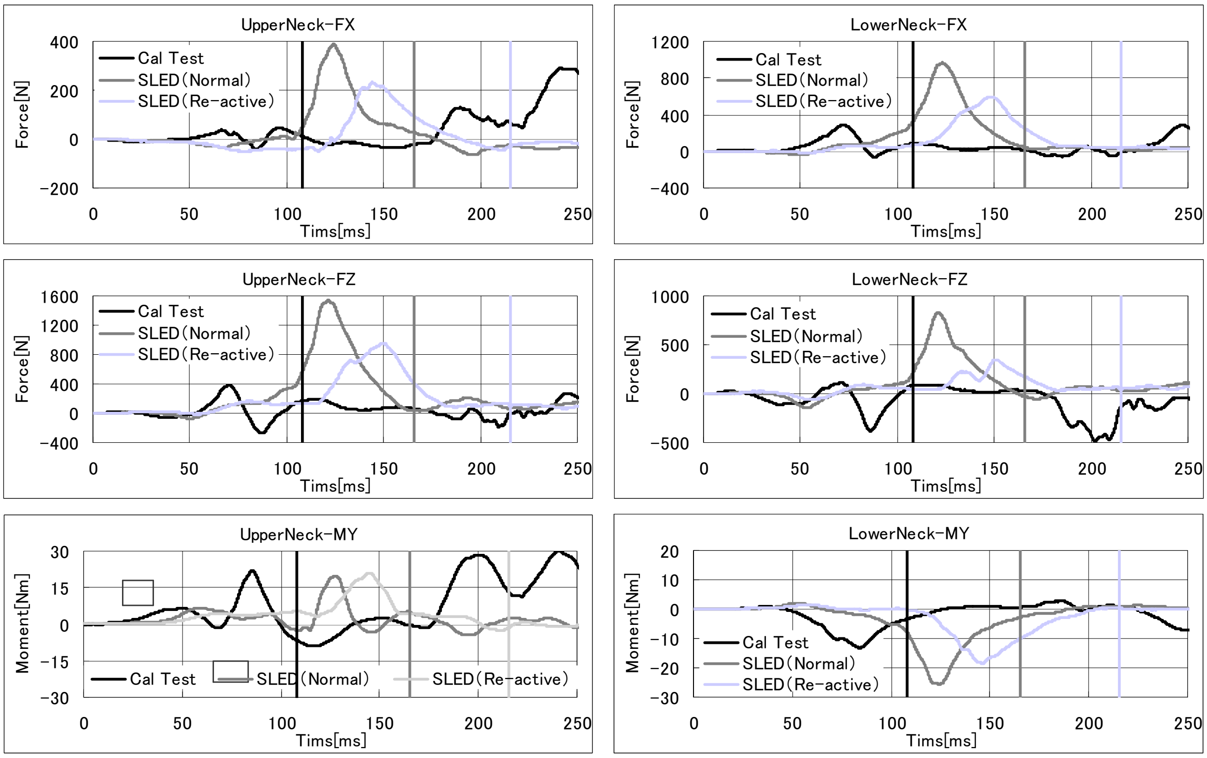


Fig.12 Comparison of Calibration Test with Headrest Results (Heavy Probe) and Sled test Results

Table.6 Comparison of Calibration Test and Sled Test (Peak Value)

	T1 Acc. [m/s²]		Upper Neck							
			FX [N]		FZ [N]		MY-Flx. [Nm]		MY-Ext. [Nm]	
	Peak Value	Time[ms]	Peak Value	Time[ms]	Peak Value	Time[ms]	Peak Value	Time[ms]	Peak Value	Time[ms]
① Light	175.7	27.5	118.4	53.3	211.7	79.5	11.8	27.8	6.9	103.7
② Heavy	112.6	57.5	47.4	96.4	383.1	70.3	21.9	85.7	9.1	116.7
Normal	133.1	105.1	386.9	123.9	1540.5	121.5	19.7	127.4	4.5	194.7
Re-active	143.3	122.2	231.6	144.1	955.8	149.7	21.0	144.8	2.5	211.9

	Lower Neck							
	FX [N]		FZ [N]		MY-Flx. [Nm]		MY-Ext. [Nm]	
	Peak Value	Time[ms]	Peak Value	Time[ms]	Peak Value	Time[ms]	Peak Value	Time[ms]
① Light	169.5	78.8	145.8	127.7	3.0	25.6	11.4	73.8
② Heavy	288.2	72.3	109.7	71.3	1.1	144.4	13.2	83.9
Normal	966.2	123.0	826.1	120.6	2.0	51.1	25.6	124.2
Re-active	597.6	148.3	345.5	150.2	1.5	55.7	18.4	146.0

V. CONCLUSIONS

For the suggested calibration tests based on this study, the BioRID-II shows good repeatability and reproducibility. In the calibration test without headrest and the calibration test with headrest (light probe), the peak responses of the waveform did not occur, and waveform configurations were also different from the representative sled test results. However, in the calibration test with headrest (heavy probe), the peak responses of the waveform were more apparent when compared with other calibration test results, and the waveform configuration was also similar to sled test results. If the calibration test for keeping good repeatability and reproducibility is selected based on this study, the calibration test with headrest (heavy probe) will be proposed because the peak and dummy's variation occurred most notably. However, in order to ensure the repeatability and reproducibility of BioRID-II, it is necessary to consider the seating procedure and experimental conditions (seat characteristic, seat configuration, etc.) so as to exclude these influences.

Moreover, the future topics identified from the present study are as follows:

・*Measurement value output levels of calibration tests*

The calibration test with headrest used with the heavy probe is the test method that can generate waveforms most resembling those of the sled test. However, the peak values and other parameters to be recorded in the calibration outputs of this test are low compared to the sled test. It is therefore necessary to develop another calibration test that will produce higher parameters to be recorded in the calibration outputs.

・*Variations of measured neck forces and moment*

The sled test has been reported to give large variations in the measured values of neck force and moment, especially in UpperNeck-FX values. Since the present test results failed to show such large variances, it is necessary to develop a calibration test method that will have more marked variations in neck forces and moments.

・*Usability of the heavy probe*

For the ease of calibration testing, it will be more desirable to use a lighter probe, but in order to better reproduce the sled test, the probe needs to be heavier.

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