HARSim: Posterior Load Comparative Analysis Process

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Abstract. Considered as a not fully appropriated way for load carriage on the spine, backpacks tend to be the elected products by students to carry their own school supplies [4]. Its use has been pointed out as a determinant aspect that contributes to the appearance of back pain and musculoskeletal disorders, mainly in growth stage children [4, 5]. Spine overload, often seen when wearing backpacks, is considered one of the main risk factor for the degeneration of intervertebral discs [1, 6, 7].

For further understanding this matter, the difficulties found in quantifying spinal acting loads, lead to the development of a considerable amount of biomechanical computerized models. The dissemination of this kind of models, lead to the need of their results evaluation as a very important aspect to consider in the selection of the most adequate software for specific study situations.

Major findings allowed to apprehend the best way to apply posterior loads onto the spine of backpack users using HARSim by dynamically comparing its results with the ones presented by Rose [2]. This paper presents all the process, allowing its reproduction and application for this type of carrying transportation system for further studies to come.

Keywords: HARSim · User experience · Posterior load transportation · Backpack

1 Introduction

Considered as a not fully appropriated way for load carriage on the spine, backpacks tend to be the elected products by students to carry their own school supplies [4]. Its use has been pointed out as a determinant aspect that contributes to the appearance of back pain and musculoskeletal disorders, mainly in growth stage children [4, 5]. Spine overload, often seen when wearing backpacks, is considered one of the main risk factors for the degeneration of intervertebral discs [1, 6, 7].

For further understanding this matter, the difficulties found in quantifying spinal acting loads, lead to the development of a considerable amount of biomechanical computerized models. Due to the fact that force transducers should not be introduced

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into the spine of alive humans these models intended to estimate the load acting in the spine of a user, during different kinds of lifting activities [1].

The dissemination of this kind of models, lead to the need of their results evaluation as a very important aspect to consider in the selection of the most adequate software for a specific study situation.

The most accurate validation process should involve the comparison of the results achieved in computerized models with the ones gathered in vivo subjects for the same anthropometrical characteristics, weight carried and activity performed. In vivo measurements are considered to be the most viable, since they provide absolute loading values [1], although this intrusive process involves a considerable amount of danger to the studied subject. So the most conscientious process to verify a model involves comparing its results with data gathered from the literature [2, 3].

Computerized biomechanical models date back to 1961, when Pearson et al. presented a two link model of the arm that intended to calculate forces and torques on shoulder and elbow [10]. Despite their evolution throughout the years, there are few biomechanical models developed considering their incorporation into the design process. One of these three-dimensional computerized models is called Humanoid Articulation Reaction Simulation (HARSim) and was specifically developed for product, workspaces and task procedures optimizations [8].

HARSim is provided with a humanoid computerized representation with 38 segments, a full spine with 24 vertebrae, and upper and lower limbs with 8 and 6 segments, respectively [8]. This humanoid model has 100 degrees of freedom, 72 for the spine, 12 for the lower limbs and 16 for the upper limbs [8]. Its model has four operational features, which include: human model generation; posture and movement simulations; geometrical objects creation; and forces, stress and strain calculation in each articulation joint [8].

When it comes to results, HARSim calculates in each articulation joint three reaction forces, one axial and two shear, and besides that it is also able to calculate three bending moments around each orthonormal reference axis along with the maximal compression force in intervertebral spaces [8]. HARSim development and validation process was thoroughly described by Rebelo et al. [8].

HARSim has already been validated with in vivo intervertebral disc pressure measurements, like the ones reported by Wilke, Neef, Hinz, et al. [1, 8] for ten activities. In this validation process none of the studied activities involved posterior load transportation, which proved to be helpful, since this software has already been used by one of the authors of this paper for studying the approximate intensity of forces applied to children's spine, while carrying their own backpacks to and from school [9].

It is intended for this study the apprehension of the best way to estimate posterior load transportation in backpacks using HARSim, by dynamically comparing its results with the ones achieved by Rose [2]. This comparison method involved the replication of the study made by Rose [2], concerning backpack transportation system, and allowed to demonstrate that HARSim results are very similar regarding force peaks in the lumbosacral region of the spine when considering anterior-posterior shear forces.

Rose [2] analyzed sixteen voluntary healthy individuals, fifty percent of which were female, with no history of lumbar back disorders. Their age ranged from 19 to 32, with a mean stature of 174, 3 cm and an average weight of 72.9 kg. Each subject carried six types of products intended for weight transportation during two levels of gait motion. Transported weight varied in each carrying activity: a no weight (NW) transportation situation; a 5, 7 kg transportation (LW); and, 11, 3 kg transportation (HW) [2].

The author justified the chosen weight range according to Kelsey, Githens et al. who stated that the repetition of an activity transporting more than 11.3 kg dramatically increased the risk of prolapsed disc. Reference [2] Being so, Rose considered 11.3 kg as the high weight (HW) transported by the studied subject and divided that by two to get a mid-range transportation weight namely (LW) of 5.7 kg.

Rose study was primarily focused on anterior-posterior (A/P) shear forces, compression, and lateral shear observed at the inferior endplates of the lumbar discs form L5/S1 to T12/L1, determined by a biologically electromyography (EMG)-assisted biomechanical model, previously described and validated.

When it comes to backpacks, Rose [2] concluded that the differences between the 11, 3 kg and the no weight transportation condition were indistinguishable. He also claimed that among the 12 studied tasks the backpack produced especially low spine loads [2] which he believes that can be attributed to the reduced arm of the moment induced by placing the load closer to the user's body weight of this product [2]. Rose [2] also claims that by distributing the weight evenly the dual-strap design of the backpack prevents the needs for muscles on one side of the body to compensate for uneven loading.

2 Method

In this paper it would only be replicated the stationary situations when wearing a backpack with no weight (NW), 5, 7 kg (LW) and 11, 3 kg (HW) transported by users.

Thanks to human model generation capability that HARSim possess, it was possible to replicate the sixteen anthropometrical profiles described by Rose [2].

For each generated model, a posture involving a dorsal and lumbar inclination of 1 and 0.5 degrees respectively was assumed. This posture simulation was achieved with the overlapping of HARSim humanoid representation with the photographic registry presented by Rose [2].

The overlapping presented before also allowed to place the weight practiced by the backpack between the T4 and L1 vertebrae (Fig. 1).

A restriction among the ZX plan in these vertebrae was needed to simulate that the force practiced by the backpack was primarily focused along the Y axis.

In order to simulate the forces practiced by the backpack and referenced by Rose [2] of 5, 7 kg and 11, 3 KG both were converted into 55,917 and 110,853 Newton's respectively. Each of these conversions were divided by two in order to obtain the force practiced by each of the backpack carrying handles (Fig. 2).

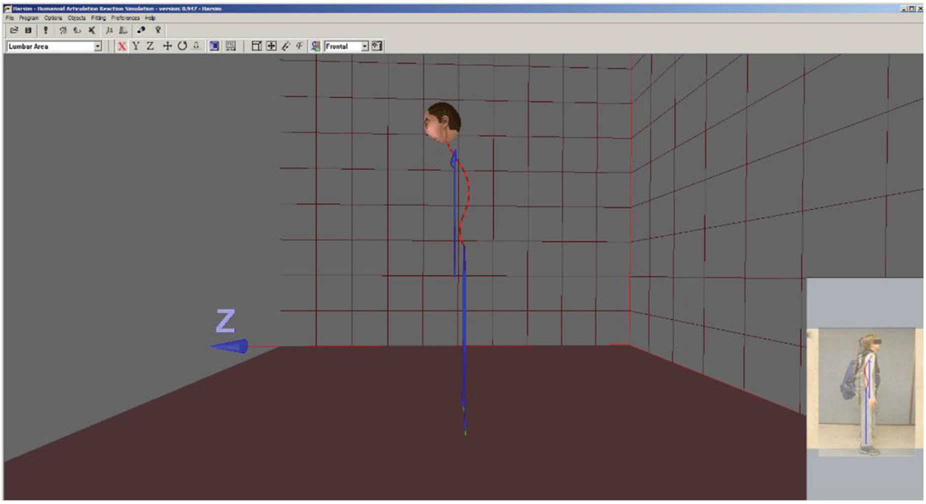

Fig. 1. Picture overlapping for posture and weight practiced by the backpack simulation

Applied on the shoulders of each HARSim humanoid model the vectors of the forces practiced by each backpack carrying handle were divided accordingly the picture below:

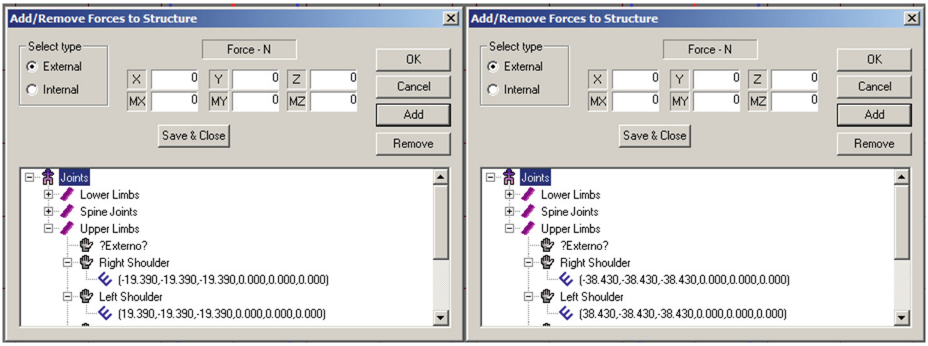

Fig. 2. 5, 7 KG (on the left) and 11, 3 kg (on the right) vectors applied on each shoulder

The process described earlier generated a humanoid model like the one presented below (Fig. 3):

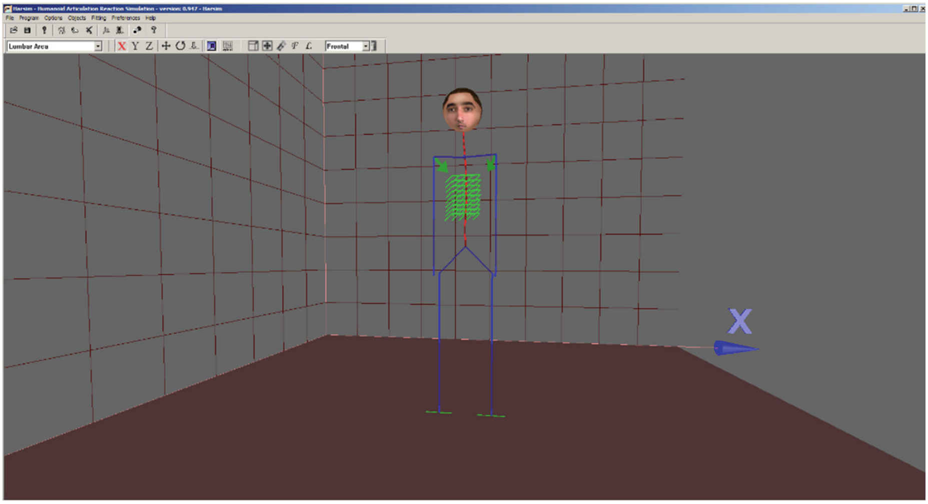

Fig. 3. HARSim humanoid model generated

3 Results

Major findings revealed that the differences are small when it comes to using a backpack to transport either 5, 7 kg or 11, 3 kg.

This paper also showed that when it comes to the cervical area of the spine there are no differences between transporting 5, 7 kg, 11, 3 kg and no weight on the backpack.

Major findings point out that the differences between transported weights (5, 7 kg and 11, 3 kg) don't interfere with the region and the vertebrae of the spine where the maximum anterior/posterior shear values occur namely the Lumbar region in the L2/L1 vertebrae and the Thoracic region on L1/T12 vertebrae. However maximum anterior/posterior shear location differences may be seen on the no weight transportation condition. Here the peaks occur in the lumbar region namely in the S1/L5 vertebrae and the thoracic region in the T2/T1 vertebrae. This location shifting where the maximum anterior/ posterior shear values occur may be justified by the placement of the load (Table 1).

Regarding compression values differences apart from the cervical spine region were found in the intensity and location regarding the three weight conditions. No weight transported condition presented higher peaks than the 5, 7 kg. Here differences were almost 90 kPa and 35 kPa lower in the lumbar (L4/L3–5, 7 kg and L1/T12 – no weight) and thoracic region (T8/T7 – 5, 7 kg and T9/T8) respectively. Higher peaks' differences

Table 1. Anterior/Posterior Shear values (Region peaks)

Joint	Shear forces (N)	Shear forces (N)	Shear forces (N)
S1 / L5	217,74	200,34	183,25
L5 / L4	92,73	62,25	32,31
L4 / L3	11,30	-26,52	-63,67
L3 / L2	85,25	130,65	175,23
L2 / L1	157,25	207,33	256,50
L1 / T12	166,31	217,11	267,00
T12 / T11	126,02	174,72	222,55
T11 / T10	91,91	138,50	184,24
T10 / T9	57,93	102,01	145,30
T9 / T8	4,19	43,40	81,90
T8 / T7	33,62	-1,46	-35,90
T7 / T6	74,86	45,11	15,88
T6 / T5	102,94	77,55	52,61
T5 / T4	134,10	114,29	94,84
T4 / T3	147,42	130,87	114,61
T3 / T2	160,94	148,13	135,56
T2 / T1	170,29	160,88	151,64
T1 / C7	71,07	71,07	71,07
C7 / C6	62,59	62,59	62,59
C6 / C5	54,69	54,69	54,69
C5 / C4	46,08	46,08	46,08
C4 / C3	34,74	34,74	34,74
C3 / C2	22,75	22,75	22,75
C2 / C1	18,49	18,49	18,49
	No Weight	5, 7 Kg	11, 3 Kg

were found when comparing the no weight transported condition with the 11, 3 kg. In the lumbar region (L4/L3) 154 kPa higher peak was found for the 11, 3 kg than the no weight transported condition. Regarding the thoracic region, the no weight transportation condition peak was 55 kPa higher than the 11, 3 kg (T7/T6) (Table 2).

Regarding lateral shear values major findings revealed very close values between the no weight and 11, 3 kg transported condition. For the lumbar region the values were the same just differing in places (S1/L5 – no weight and L3/L2 – 11, 3 kg), and for the thoracic region the difference was around 6 N/m higher in the no weight transported

Table 2. Compression values (Region peaks)

Joint	Stress (kPa)	Stress (kPa)	Stress (kPa)
S1 / L5	430,59	300,66	426,71
L5 / L4	430,61	352,40	611,88
L4 / L3	376,48	382,67	622,01
L3 / L2	358,99	351,60	565,05
L2 / L1	388,91	254,71	438,36
L1 / T12	468,66	333,87	282,18
T12 / T11	537,77	426,26	316,76
T11 / T10	587,56	498,02	410,10
T10 / T9	621,94	553,48	486,25
T9 / T8	641,32	594,05	547,63
T8 / T7	635,52	606,39	577,78
T7 / T6	611,55	598,92	586,52
T6 / T5	569,97	570,90	571,82
T5 / T4	514,28	527,00	539,49
T4 / T3	448,55	470,00	491,07
T3 / T2	376,43	405,22	433,50
T2 / T1	299,29	333,70	367,49
T1 / C7	147,83	147,83	147,83
C7 / C6	124,36	124,36	124,36
C6 / C5	102,65	102,65	102,65
C5 / C4	83,14	83,14	83,14
C4 / C3	66,70	66,70	66,70
C3 / C2	52,73	52,73	52,73
C2 / C1	39,20	39,20	39,20
	No Weight	5, 7 Kg	11, 3 Kg

condition (T8/T7 – no weight and T7/T6 – 11, 3 kg). When it comes to the 5, 7 kg transported condition it registered the minimum value for the lumbar region (L3/L2) with a 14 N/ m difference for the other two weight conditions. The thoracic region (T7/T6) was almost the mean value for the other two weight transported conditions (Table 3).

4 Discussion

Enlarging analysis spectrum, incorporating all spine regions, this study results' meet with most of the findings presented by Rose [2] regarding the backpack transportation system.

Table 3. Lateral Shear values (Region peaks)

Joint	Moment XX (N/m)	Moment XX (N/m)	Moment XX (N/m)
S1 / L5	20,98	3,25	-10,32
L5 / L4	12,21	-3,26	-16,02
L4 / L3	8,47	-5,19	-17,02
L3 / L2	-6,50	6,26	20,28
L2 / L1	-9,15	1,00	13,22
L1 / T12	-14,04	-6,14	2,87
T12 / T11	-17,77	-11,01	-4,37
T11 / T10	-20,60	-14,93	-9,37
T10 / T9	-22,67	-18,04	-13,50
T9 / T8	-23,97	-20,33	-16,76
T8 / T7	30,79	27,04	23,36
T7 / T6	29,81	27,08	24,41
T6 / T5	27,63	25,77	23,95
T5 / T4	24,63	23,51	22,41
T4 / T3	20,72	20,18	19,65
T3 / T2	16,43	16,37	16,31
T2 / T1	11,75	12,06	12,37
T1 / C7	5,36	5,36	5,36
C7 / C6	4,14	4,14	4,14
C6 / C5	3,05	3,05	3,05
C5 / C4	2,11	2,11	2,11
C4 / C3	1,31	1,31	1,31
C3 / C2	0,71	0,71	0,71
C2 / C1	0,32	0,32	0,32
	No Weight	5, 7 Kg	11, 3 Kg

Considering maximum peak forces for all weights carried Tables 4, 5 and 6 shows that there were not found significant differences between them. However no weight carried situation from Rose's [2] study present an acting vertebrae peak closer to the ones obtained by our results.

Table 4. Anterior/Posterior Shear values (Region peaks) comparison

Joint	Reference A/ P shear values - Rose [2]	Shear forces (N)	Reference A/ P shear values - Rose [2]	Shear forces (N)	Reference A/ P shear values - Rose [2]	Shear forces (N)
S1 / L5	240,40	217,74	261,90	200,34	301,80	183,25
L5 / L4	61,20	92,73	76,30	62,25	89,50	32,31
L4 / L3	172,50	11,30	165,50	-26,52	179,30	-63,67
L3 / L2	251,00	85,25	246,90	130,65	272,10	175,23
L2 / L1	273,40	157,25	270,00	207,33	298,80	256,50
L1 / T12	255,10	166,31	251,00	217,11	277,30	267,00
T12 / T11	N.A.	126,02	N.A.	174,72	N.A.	222,55
T11 / T10	N.A.	91,91	N.A.	138,50	N.A.	184,24
T10 / T9	N.A.	57,93	N.A.	102,01	N.A.	145,30
T9 / T8	N.A.	4,19	N.A.	43,40	N.A.	81,90
T8 / T7	N.A.	33,62	N.A.	-1,46	N.A.	-35,90
T7 / T6	N.A.	74,86	N.A.	45,11	N.A.	15,88
T6 / T5	N.A.	102,94	N.A.	77,55	N.A.	52,61
T5 / T4	N.A.	134,10	N.A.	114,29	N.A.	94,84
T4 / T3	N.A.	147,42	N.A.	130,87	N.A.	114,61
T3 / T2	N.A.	160,94	N.A.	148,13	N.A.	135,56
T2 / T1	N.A.	170,29	N.A.	160,88	N.A.	151,64
T1 / C7	N.A.	71,07	N.A.	71,07	N.A.	71,07
C7 / C6	N.A.	62,59	N.A.	62,59	N.A.	62,59
C6 / C5	N.A.	54,69	N.A.	54,69	N.A.	54,69
C5 / C4	N.A.	46,08	N.A.	46,08	N.A.	46,08
C4 / C3	N.A.	34,74	N.A.	34,74	N.A.	34,74
C3 / C2	N.A.	22,75	N.A.	22,75	N.A.	22,75
C2 / C1	N.A.	18,49	N.A.	18,49	N.A.	18,49
	No Weight	No Weight	5, 7 Kg	5, 7 Kg	11, 3 Kg	11, 3 Kg

Table 5. Compression values (Region peaks) comparison

Joint	Reference compression values - Rose [2]	Stress (kPa)	Reference compression values - Rose [2]	Stress (kPa)	Reference compression values - Rose [2]	Stress (kPa)
S1 / L5	395,20	430,59	417,50	300,66	465,70	426,71
L5 / L4	456,70	430,61	484,60	352,40	545,40	611,88
L4 / L3	424,20	376,48	458,10	382,67	519,50	622,01
L3 / L2	380,20	358,99	416,80	351,60	473,90	565,05
L2 / L1	361,20	388,91	399,00	254,71	454,10	438,36
L1 / T12	374,90	468,66	411,60	333,87	468,70	282,18
T12 / T11	N.A.	537,77	N.A.	426,26	N.A.	316,76
T11 / T10	N.A.	587,56	N.A.	498,02	N.A.	410,10
T10 / T9	N.A.	621,94	N.A.	553,48	N.A.	486,25
T9 / T8	N.A.	641,32	N.A.	594,05	N.A.	547,63
T8 / T7	N.A.	635,52	N.A.	606,39	N.A.	577,78
T7 / T6	N.A.	611,55	N.A.	598,92	N.A.	586,52
T6 / T5	N.A.	569,97	N.A.	570,90	N.A.	571,82
T5 / T4	N.A.	514,28	N.A.	527,00	N.A.	539,49
T4 / T3	N.A.	448,55	N.A.	470,00	N.A.	491,07
T3 / T2	N.A.	376,43	N.A.	405,22	N.A.	433,50
T2 / T1	N.A.	299,29	N.A.	333,70	N.A.	367,49
T1 / C7	N.A.	147,83	N.A.	147,83	N.A.	147,83
C7 / C6	N.A.	124,36	N.A.	124,36	N.A.	124,36
C6 / C5	N.A.	102,65	N.A.	102,65	N.A.	102,65
C5 / C4	N.A.	83,14	N.A.	83,14	N.A.	83,14
C4 / C3	N.A.	66,70	N.A.	66,70	N.A.	66,70
C3 / C2	N.A.	52,73	N.A.	52,73	N.A.	52,73
C2 / C1	N.A.	39,20	N.A.	39,20	N.A.	39,20
	No Weight	No Weight	5, 7 Kg	5, 7 Kg	11, 3 Kg	11, 3 Kg

Table 6. Lateral Shear values (Region peaks) comparison

Joint	Reference lateral shear values - Rose [2]	Moment XX (N/m)	Reference lateral shear values - Rose [2]	Moment XX (N/m)	Reference lateral shear values - Rose [2]	Moment XX (N/m)
S1 / L5	6,40	20,98	8,30	3,25	10,80	-10,32
L5 / L4	6,50	12,21	9,30	-3,26	11,20	-16,02
L4 / L3	6,60	8,47	12,10	-5,19	13,30	-17,02
L3 / L2	6,90	-6,50	13,40	6,26	15,60	20,28
L2 / L1	7,20	-9,15	14,30	1,00	17,90	13,22
L1 / T12	7,40	-14,04	15,60	-6,14	21,00	2,87
T12 / T11	N.A.	-17,77	N.A.	-11,01	N.A.	-4,37
T11 / T10	N.A.	-20,60	N.A.	-14,93	N.A.	-9,37
T10 / T9	N.A.	-22,67	N.A.	-18,04	N.A.	-13,50
T9 / T8	N.A.	-23,97	N.A.	-20,33	N.A.	-16,76
T8 / T7	N.A.	30,79	N.A.	27,04	N.A.	23,36
T7 / T6	N.A.	29,81	N.A.	27,08	N.A.	24,41
T6 / T5	N.A.	27,63	N.A.	25,77	N.A.	23,95
T5 / T4	N.A.	24,63	N.A.	23,51	N.A.	22,41
T4 / T3	N.A.	20,72	N.A.	20,18	N.A.	19,65
T3 / T2	N.A.	16,43	N.A.	16,37	N.A.	16,31
T2 / T1	N.A.	11,75	N.A.	12,06	N.A.	12,37
T1 / C7	N.A.	5,36	N.A.	5,36	N.A.	5,36
C7 / C6	N.A.	4,14	N.A.	4,14	N.A.	4,14
C6 / C5	N.A.	3,05	N.A.	3,05	N.A.	3,05
C5 / C4	N.A.	2,11	N.A.	2,11	N.A.	2,11
C4 / C3	N.A.	1,31	N.A.	1,31	N.A.	1,31
C3 / C2	N.A.	0,71	N.A.	0,71	N.A.	0,71
C2 / C1	N.A.	0,32	N.A.	0,32	N.A.	0,32
	No Weight	No Weight	5, 7 Kg	5, 7 Kg	11, 3 Kg	11, 3 Kg

5 Conclusions

Major findings revealed that when it comes to the cervical region of the spine weight differences do not interfere with its values in none of the analyzed forces (compression, anterior/ posterior and lateral shear).

This study also found that an increase of the transported weight in a backpack don't interfere with the vertebrae where the maximum peak force tend to occur.

When comparing weight (5, 7 kg and 11, 3 kg) with the no weight transported condition it was also found that the vertebrae where the maximum peak force occurs tend to come closer to the location of the load regarding anterior/ posterior and lateral shear values.

Since most of the results were coherent with the ones gathered by Rose [2] we may assume that this process to obtain spinal reaction forces in HARSim when transporting a backpack is correct.

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