Evaluation of school backpack prototype-based on gait parameters, energy expenditure and posture of students

Ishant Gupta[1,*], Parveen Kalra[1] and Rauf Iqbal[2]

[1]Center of Excellence in Industrial & Product Design, PEC University of Technology, Chandigarh 160 012, India
[2]National Institute of Industrial Engineering, Powai, Mumbai 400 087, India

Carrying of backpacks by school going children leads to postural and gait adaptations, leading to falls, imbalances, low back pain and musculoskeletal disorders. This study examined gait parameters, posture and energy expenditure differences between the modified backpack (MBP) and the existing backpacks (EBPs) in school students. Using portable gait system, 26 healthy participants performed the trials with three loading conditions of 10%, 20% and 30% of their body weight (BW) with the two different categories of backpacks. There was significant difference in cadence, double support time, ground impact, energy expenditure and anterior lean angle between no-load condition and the backpacks. Relative to the no-load condition, energy expenditure (EE) increased by 4.26 cal/min, and anterior lean angle (ALA) increased by 6.90° for the EBPs at 30% load condition whereas EE increased by 2.83 calories/min and ALA by 4.43° in case of MBP at 30% condition. The results indicate that parameters recorded while carrying MBP resembled the those recorded during no-load condition. The erect posture, natural gait patterns and reduction in energy consumption supported by the MBP may thus reduce the causes of back pain and fatigue among school children.

Keywords: Backpack design, trunk angle, natural spine, school children, back pain.

BACKPACK is a common product used by athletes, soldiers, and students. According to a report by the Ministry of the Human Resource Development (MHRD), 191 million students in India going to school use backpacks on a daily basis[1]. Backpacks are a better option when compared to carrying the load in hands, over the head or using front-packs, because they may reduce physiological and bio-mechanical demand compared to other load carrying methods[2–5] and free the hands/arms for other purposes. However, due to various reasons, backpack is the only practical option for school children to carry their items. There has been growing concern about improper use of backpacks (excessive or unilateral loading) which has led to adverse consequences such as variation in gait, excessive energy consumption, disorders in the neck and back and kyphosis[6–9].

Over the years, several studies have examined the bio-mechanical and physiological responses to backpacks by school children[10–13]. Although several studies have reported the effects of backpacks carried by students on energy expenditure and kinematics of gait[14–17], few studies focus on the comparison of different designs of the backpacks for school.

Various studies used physiological measurements or rate of perceived exertion (RPE) to evaluate the effects of backpacks. Bobet and Norman[18] reported that physiological measurements are not sufficient for the actual assessment of effort done by muscle load when carrying heavy weights. Therefore, it is important to go into the etiology of musculoskeletal disorders that occur while carrying the school backpack. Connolly *et al.*[19] reported high variations in gait parameters while carrying a school backpack over 1 shoulder or 2 shoulders with two different loading conditions. However, continuous variations in gait parameters can lead to musculoskeletal imbalances and disorders. Kim *et al.*[20] evaluated the design of military backpack with the use of gait kinematics, muscle activity and forces on shoulders and other regions. They also suggested that energy expenditure while carrying different designs of backpacks should be examined.

Studies have reported the correlation of backpack design, backpack weight, distribution of forces down the back, duration of carrying, postural adjustments, metabolic cost, and gait changes while carrying the backpack with musculoskeletal injuries[21–26]. Studies have proved that placing the backpack load closer to the body's center of mass (CoM) results in a variation in gait parameters and a reduction in energy expenditure[27–30]. It further reduces the probability of disorders among school children carrying such backpacks.

By maintaining the posture during the loaded condition around the plumb line/vertical axis similar to the neutral posture (unloaded condition), a modified design of the school backpack seeks to reduce, higher bio-mechanical strains, gait variation, and metabolic cost seen in the existing designs of backpacks carried by students. Few studies tried to improve the design of school backpacks by distributing the load both in the front and back of the participants and reported smaller muscle activity in the muscles surrounding the spine and decreased vascular requirements compared to existing backpacks[31]. Alternatively, a study conducted for front pack design reported higher muscular activity in the erector spine muscles, whereas there was only slight decrease in the muscle activity of rectus abdominis muscle[32] compared to backpacks. Furthermore, a significant increase in thoracic kyphosis was also seen while carrying front packs. However, Lloyd and Cooke[33] also used the counterbalance backpacks, which distributed the load between the front and back of the participants investigated resulting

*For correspondence. (e-mail: igupta3423@gmail.com)

Table 1. Summary of physical parameters of the groups

Groups	Mean age (SD)	Mean weight (SD)	Mean height (SD)	Mean BMI (SD)
G	12.3 (1.09)	43.4 (3.7)	1.43 (0.063)	21.2 (1.27)

Figure 1. Modified backpack used in the study.

in significant decrease in trunk angle and smaller CoM displacement.

The principal objective of this study was to assess the gait adjustments and energy consumption that results while carrying the existing backpacks and a modified backpack (an internal frame backpack based on the principle of spinal kinematics). Additionally, the effect of both backpacks (existing and modified) on the anterior lean of the trunk during a static stance at different loading conditions was examined. The hypothesis of this study was that the modified design backpack would have lesser variations in gait parameters and a reduction in energy expenditure. It was also hypothesized that anterior lean of the trunk in the sagittal plane in persons who used modified backpacks was less than those who used the existing backpacks.

Fifty four subjects (34 males and 20 females) representing a single age group were selected from two different schools (Table 1). Eighteen students from each grade (i.e. from sixth to eighth grade) were selected with similar body mass index (BMI) of 20 to 23. Prior to data collection, the protocol was explained to the participants and to their parents/guardians. A consent form was signed by fifteen participants and one of their parents/guardians. The study procedures and measurements had approval (NK/3399/Study) from the ethics committee of PEC University of Technology and Department of Physical and Rehabilitation Medicine of the Post Graduate Institute of Medical Education and Research (PGIMER), Chandigarh, India. Of the 70 participants, only 54 were selected for the study. They had no history of musculo-skeletal, orthopaedic or neurological disorders as verified by a physician. All the experiments were conducted in the gait lab at the Department of Physical and Rehabilitation Medicine in PGIMER. Orthopaedic or neurological disorders were verified by the physician.

Gait parameters and trunk anterior lean were captured by using Intelligent Device for Energy Expenditure and Activity (IDEEA) portable gait system (Minisun Inc., Fresno, California, USA). Each participant used a different brand of backpack for regular use. The existing backpacks used by participants were without any ergonomic features such as for hip or chest belts (Figure 1 *a*). On the other hand, the design of the modified backpack with an internal frame which mimics the kinematics of spine, distributes the load evenly along the trunk. The modified backpack which also allows the user to move freely in 6 degrees of freedom without any constraint is presented in Figure 1. The load was evenly distributed in the backpacks; the heavier books/textbooks were placed closer to the spine, and the lighter books were placed away from it. Shoulder straps of the backpacks were adjusted to the extent, where the tip of the backpack was positioned at 2 cm above the waistline of the participant.

With the development of the MBP, it is necessary to determine exactly how the backpack will perform. To accomplish this task, a series of validation processes used to determine the functionality of the prototype, are outlined in Table 2. The parameters were chosen based on studies discussed in the literature review; the various methods of measuring each parameter were also based on these studies. To quantify the desired effect of the backpack on each parameter, values were generally based on results from previous studies on the existing backpack systems. In cases where a quantifiable value could not be measured reliably, the parameter was evaluated qualitatively by comparing its value with different test conditions. Table 1 includes all the parameters chosen for functionality evaluation of MBP.

Anthropometric measurements, height and weight were recorded by manual stadiometer and digital weighing

Table 2. Validation processes chosen for the functionality evaluation of the backpack prototype

Validation process	Parameter
Posture	Trunk forward lean
Gait assessment	Velocity (m/s), step length (cm), stride length (cm), cadence (steps/min), swing duration (s), stance duration (s), initial double limb support (%), single limb support (%), ground impact (G)
Energy	Consumption energy expenditure in calorie/min

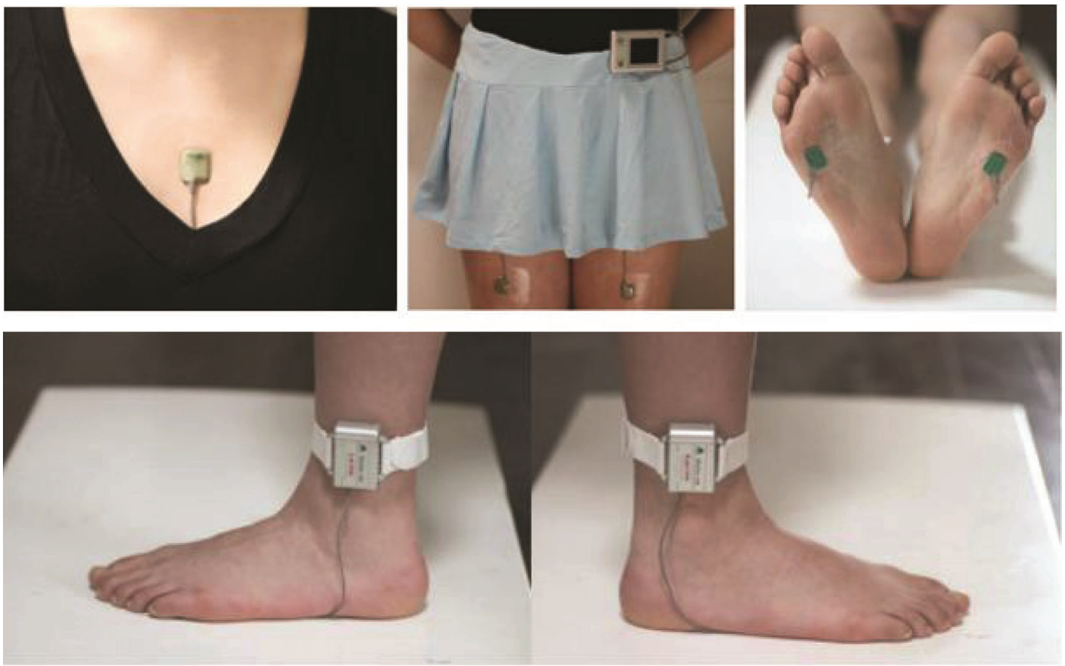

Figure 2. IDEEA sensor placement on the anterior sternum, anterior aspect of thighs and plantar surface of each foot, on the lateral side of the foot arch.

machine. Gait parameters, trunk lean angle and energy expenditure were recorded with IDEEA system. It is an accelerometre system consisting of 5 biaxial sensors (one placed on the chest, two sensors placed on each of the thighs, and two sensors placed on the planar surface of each foot) (Figure 2).

Participants completed seven sessions of data recording: initially data recorded was for a no-load condition which was considered as the baseline value for all recorded parameters. Then data was recorded for three load conditions with their existing backpacks; the other three load conditions were with modified design backpacks. In the first session, participants were asked to walk under no load condition. For the next six sessions, participants walked while carrying the load of 10%, 20% and 30% of wearer's body weight (BW). For each participant, these sessions were recorded in a random order on different days to minimize the learning effects and possible order effects. Two backpacks were carried by each participant for 25 min at their natural walking speed: one, their individual existing backpacks, and the other, the modified backpack. The anterior lean of the trunk was measured during the stance phase of the gait at the start and end of the gait cycle, during walking under each loading condition. Anterior lean angle was calculated relative to the trunk. The recording of the gait parameters, anterior lean angle, and energy expenditure while walking with no-load were treated as the baseline values for each parameter.

To accurately determine the performance of the backpack, data must be collected from a controlled experiment. The following experimental design outlines the methods and materials required to properly collect data on the modified backpack and on an existing backpack. Overall, data were collected from two separate experiments for each subject. The first experiment was designed to collect posture, gait and energy expenditure data to determine the efficacy of the modified backpack compared to the existing backpacks.

The experimental task sequence was as follows: (i) Measurement of anthropometric data of subjects; (ii) walking trails of the subjects at their natural speed for the no-load condition to measure the gait parameters, lean

Table 3. Mean (standard deviation) of response parameters for no load, 10%, 20% and 30% of BW backpack load obtained while carrying a modified backpack and an existing backpack (n = 20)

Variables	Statistical features	No load	EBPs 10%	MBP 10%	EBPs 20%	MBP 20%	EBPs 30%	MBP 30%
Velocity (m/s)	Mean (SD)	1.12 (0.16)	1.17 (0.15)	1.14 (0.18)	1.09 (0.11)	1.13 (0.15)	1.06 (0.09)	1.09 (0.13)
Step length (cm)	Mean (SD)	62.4 (5.3)	64.8 (5.9)	67.7 (6.1)	63.6 (7.4)	64.5 (8.3)	61.5 (4.9)	61.7 (5.8)
Stride length (cm)	Mean (SD)	132.4 (10.3)	133.6 (11.1)	133.8 (11.5)	129.4 (12.7)	131.9 (13.2)	129.4 (14.3)	130.7 (14.5)
Cadence (steps/min)	Mean (SD)	104.5 (6.2)	102.2 (7.5)	103.8 (7.2)	102.7 (7.7)	101.5 (7.9)	99.2 (8.5)	100.4 (8.7)
Swing duration (s)	Mean (SD)	0.38 (0.03)	0.41 (0.05)	0.39 (0.03)	0.37 (0.06)	0.38 (0.07)	0.41 (0.07)	0.42 (0.08)
Stance duration (s)	Mean (SD)	0.59 (0.04)	0.62 (0.06)	0.61 (0.08)	0.66 (0.07)	0.62 (0.08)	0.69 (0.09)	0.64 (0.08)
Initial double limb support (%)	Mean (SD)	12.73 (1.24)	12.89 (1.87)	12.76 (1.91)	12.98 (1.94)	13.08 (2.01)	13.76 (2.45)	13.09 (2.23)
Single limb support (%)	Mean (SD)	35.73 (1.98)	36.59 (2.12)	36.34 (2.13)	36.49 (2.24)	36.85 (3.07)	36.47 (2.87)	36.18 (2.49)
Ground impact (G)	Mean (SD)	0.98 (0.05)	1.07 (0.12)	1.04 (0.09)	1.12 (0.15)	1.05 (0.12)	1.27 (0.21)	1.21 (0.17)
Anterior lean angle (deg)	Mean (SD)	1.78 (0.97)	4.21 (2.43)	4.33 (2.47)	6.85 (3.88)	5.07 (3.66)	8.68 (4.04)	6.21 (4.97)
Energy expenditure (cal/min)	Mean (SD)	4.13 (0.83)	4.71 (0.72)	4.82 (0.88)	5.37 (0.95)	5.71 (0.95)	8.39 (0.81)	6.96 (0.82)

NL, No load carriage; MBP 10%, Modified backpack at 10% loading condition; EBPs 10%, Existing backpacks at 10% loading condition; MBP 20%, Modified backpack at 20% loading condition; EBPs 10%, Existing backpacks at 10% loading condition; MBP 30%, Modified backpack at 30% loading condition; EBPs 30%, Existing backpacks at 30% loading condition.

angle, and energy expenditure for 25 min; (iii) the subject was given a recovery time of at least 60 min; (iv) participants choose either their existing backpack or the modified backpack; (v) random selection of load condition of 10%, 20%, 30% of BW by participants. The order of load conditions was chosen randomly in order to reduce learning effects; (vi) standing trial was performed for 15 s with either backpack while carrying any load to measure response parameters; (vii) the walking trial at their natural speed was conducted for 25 min while carrying any backpack with any load condition to measure the response parameter; (viii) repeat steps from i–vii, till trial with both kinds of back packs under all load conditions are completed.

Nine gait parameters, energy expenditure and anterior lean of the trunk responses were collected. The data were normalized by using the variation of baseline response parameters in terms of percentage. For analysing the effect of all the recorded parameters measured during the different loading conditions (10%, 20% and 30% of BW) with the existing backpacks and with modified backpacks, the parameters recorded were compared with the baseline (no-load condition) values. They were analysed using separate one-way repeated measure ANOVA statistical technique. Data was collected for three different loads three times. For analysing the difference between the existing backpacks and a modified backpack 2 × 3 (backpack types × loading conditions) repeated measures were analysed by ANOVA technique with a turkey post-hoc differences. The software Statistical Package for Social Sciences (SPSS, version 19.0) was used for analysis, and the value of alpha was set at $P < 0.05$.

A summary of mean response parameters recorded during walking, viz. gait parameters, energy consumption and anterior lean angle of the trunk, is shown in Table 3. Turkey, post-hoc differences for comparisons of the two backpacks at different loading conditions and with no-load condition defining significant differences, are presented in Table 4.

Comparison of responses to both backpack types under each loading condition showed significant differences. The participants while carrying the EBPs had to enforce higher deceleration in a vertical direction during the heel strike than those carrying the same load in the MBP. Backpack type and load had a significant effect on Double Limb Support (DLS); modified backpack carrier had a lower DLS duration at 30% load condition than an existing backpack carrier. Cadence decreased significantly between 20% and 30% load conditions in the existing back pack carriers compared to modified backpack carriers. There was a significant effect of backpack type and load conditions on anterior lean angle and energy expenditure. The modified backpack, for 20% and 30% load condition, elicited more upright trunk posture at heel strike than the existing backpack. The anterior lean angle for the unloaded condition was significantly lower than for either of the backpacks under different load conditions. Trunk angle became significantly leaner toward anterior side when wearing MBP compared to EBP and as load increased from 10% to 20% and 20% to 30% (Table 3). There was significant interaction between backpack and load on trunk angle. At different loads, trunk angle showed sharper increase for EBP than MBP in pre- and post-walk conditions. However, there was no significant effect of the backpack type as load increased from NL to 10%. The energy consumption showed significant effect as the load increased. No difference was seen for backpack type at load conditions of 10% and 20%, whereas a significant difference in energy consumption was seen at 30% load.

In this study, a new load carriage system for school going children was tested and compared with the existing or currently used backpacks used by school going children. The main objectives of designing the modified

Table 4. Turkey *post hoc* comparisons of significant response parameters for modified backpack and existing backpack carried by participants at 10%, 20% and 30% of BW loading condition and unloaded condition ($n = 20$)

Parameters	Load condition	*Post hoc* differences	Significance
Cadence	30%	NL ↑ MBP	$P < 0.05$
		NL ↑ EBP	$P < 0.05$
	30%	MBP ↑ EBP	$P < 0.05$
Initial double limb support	30%	MBP ↑ NL	$P < 0.05$
		EBP ↑ NL	$P < 0.05$
	30%	EBP ↑ MBP	$P < 0.05$
Ground impact	10%, 20% and 30%	MBP ↑ NL	$P < 0.05$
		EBP ↑ NL	$P < 0.05$
	20% and 30%	EBP ↑ MBP	$P < 0.05$
Anterior lean angle	10%, 20% and 30%	MBP ↑ NL	$P < 0.05$
		EBP ↑ NL	$P < 0.05$
	20% and 30%	EBP ↑ MBP	$P < 0.05$
Energy expenditure	10%, 20% and 30%	MBP ↑ NL	$P < 0.05$
		EBP ↑ NL	$P < 0.05$
	30%	EBP ↑ MBP	$P < 0.05$

NL, No load; MBP, Modified backpack; EBP, Existing backpack. The pairwise comparisons are broken down to show where significant differences occurred for each variable during experimental trials.

backpack were to maintain natural gait and posture and reduce the metabolic fatigue among school going children. The hypothesis of this study was that MBP would provide natural gait pattern, upright posture for selected load conditions. Energy consumption was hypothesized to be less for MBP.

During the experiment, gait changes were seen among participants while carrying MBP and the EBPs. In this study, the ground impact increased with load while walking regardless of the backpack type. There was more ground impact by users of EBPs than those who used MBP at loading conditions of 20% and 30% BW. This may be because the internal frame of MBP offloaded the weight to body regions, while EBPs transferred weight directly to the body. The EBPs oscillated during walking as these backpacks had no rigidity and support. Therefore, the CoM of these backpacks was not close to the CoM of the user, which caused imbalances in the posture and gait of the participants. The MBP, however, provided a snug fit to hold the load closer to the CoM of the user and reduce unwanted oscillations of the backpack, allowing the participants to maintain a better balance and reduce the postural adaptations. The natural gait permits may reduce the likelihood of imbalance and fall. Additionally lesser double support time for the MBP compared to EBPs at 30% load condition may be related to the snug fit. The reduction in the vertical movement (oscillations) contributed to the reduction in forces exerted during the expensive double support phase of the gait cycle. The cadence was decreased significantly only at 30% load condition compared to an unloaded condition. The EBP carriers had a lower cadence in contrast to MBP carriers only at 30% load condition. In contrast to these findings, Chow *et al.*[34] found that walking speed and cadence decreased significantly with increasing backpack load, while double support time increased[34]. However, Cassidy *et al.*[35] also developed an experimental backpack and compared that backpack with existing backpacks. They reported reduction in ground reaction forces for the experimental backpack, which is similar to our findings[35]. Other studies also discussed variations in gait with the carriage of the load.

The performance specification of MBP was to decrease fatigue with respect to the EBP. Tables 2 and 3 show a statistical comparison of the results of energy expenditure between EBP and MBP. The physical assessment of fatigue is estimated using IDEEA portable gait sensors. The mental assessment of fatigue is based on subject RPE questionnaire given to carriers post-testing under each backpack condition.

In this study, energy expenditure while carrying MBP was significantly less than while carrying EPB at 30% load condition. The energy expenditure at 30% load condition reduced by 20.5% with the use of MBP than EBP. However, there was no significant difference in energy expenditure between the two types at other loading conditions (10% and 20%). In contrast to these findings, Legg *et al.*[30] and Kirk *et al.*[36] found no significant differences in energy expenditure of different packs carried on the trunk by male subjects[30,36]. Ramadan *et al.*[32] studied the subjective participant's exertions for a modified designed backpack and commercial backpack. They found that participants felt more comfortable when wearing the modified backpack than the commercial backpack. In general, this study suggested that improvement in the design of backpack can reduce muscular exertion which is an indirect indicator of energy expenditure. Our observations are consistent with these findings.

During walking, postural changes were seen between the two types of backpacks. At 20% and 30% load conditions, there was less forward trunk angle for the MBP than the EBP. This likely resulted from posterior support provided by the frame. MBP, however, placed the load in line with vertical axis. The CoM of MBP, also close to the body, allowed the carrier to maintain a more upright torso position. A more erect stance permits a more natural spine curvature and thus may help reduce the likelihood of low back pain caused by flattening of the lumbar spine with trunk flexion[37]. The freedom of movement provided by the MBP allows the wearer to mimic the kinematics of the spine which permits the wearer a more natural spine curvature. Consequently, with EBP resulting in more forward trunk lean, the head position was hyperextended than MBP, which may result in shoulder and neck pain[38,39]. Hyperextension also places undue stress on cervical vertebrae by removing the natural shock absorbing curvature and sends the weight of the head straight to the discs and posterior facets. When standing without a backpack, immediately after walking with one of the packs, differences between the packs were still present. Trunk angle was significantly more flexed in the MBP carrier than in EBP. Trunk angle continued to be affected by load. Other studies also reported worsening posture with increased load[38,40,41]. Pre- and post-walk differences in trunk angle may indicate a residual effect of walking with a backpack.

In this study, a new load carriage system (modified back pack) for school children was tested and compared with a commercially available backpack by using gait, postural and fatigue assessments. With the main objective of reducing injury and fatigue among students, this new design incorporated a frame having an inter-regional ball joint. The kinematics of frame resembles that of the spine as far as its inter-segmental divisions are concerned. The height of the internal frame is adjustable through use of a sliding mechanism. The frame has same degrees of freedom as the actual spinal regions. This allows the user to bend, arch and twist without any constraint even when the backpack is being carried. The compartment part of the frame adjusts the book items in an inclined way for better distribution of weight. Gait assessment, anterior trunk angle, and energy expenditure were measured through a series of subject tests to compare the two backpacks quantitatively. Ultimately, MBP slightly reduced the user fatigue as observed in a quantitative test. However, MBP allows the wearer to maintain a more upright posture than EBP, while not equal to the NL condition. The gait parameters while carrying MBP were not always significantly different from EBP, but the parameters recorded during the carriage of MBP more closely resembled the participant's natural gait patterns as determined by the NL condition. Reduction in energy consumption in the case of MBP at 30% BW load condition decreases the metabolic cost which further improves the rate of perceived exertion for the users while carrying heavy weight.

Conflict of interest: In this study, there was no conflict of interest among any authors and financing organization.

1. MHRD, 2013; http://mhrd.gov.in/Department of School Education and Literacy/AR2015-16.pdf
2. Forjuoh, S. N., Lane, B. L. and Schuchmann, J. A., Percentage of body weight carried by students in their school backpacks. *Am. J. Phys. Med. Rehabil.*, 2003, **82**, 261–266.
3. Goodgold, S., Corcoran, M., Gamache, D., Gillis, J., Guerin, J. and Coyle, J. Q., Backpack use in children. *Pediatr. Phys. Ther.*, 2002, **14**, 122–131.
4. Grimmer, K. and Williams, M., Gender-age environmental associates of adolescent low back pain. *Appl. Ergon.*, 2000, **31**, 343–360.
5. Whittfield, J. K., Legg, S. J. and Hedderley, D. I., The weight and use of schoolbags in New Zealand secondary schools. *Ergonomics*, 2001, **44**, 819–824.
6. Abrahams, S., Ellapen, T. J., Van Heerden, H. J. and Vanker, R., The impact of habitual school bag carriage on the health of pubescent scholars. *Afr. J. Phys. Health Educ. Recr.. Dance*, 2001, **17**, 762–771.
7. Linders, D. R. and Nuckley, D. J., Deduction of spinal loading from vertebral body surface strain measurements. *Exp. Mech.*, 2007, **47**, 303–310.
8. Orloff, H. A. and Rapp, C. M., The effects of load carriage on spinal curvature and posture. *Spine*, 2004, **29**, 1325–1329.
9. Bettany-Saltikov, J. and Cole, L., The effect of frontpacks, shoulder bags and handheld bags on 3D back shape and posture in young university students: an ISIS2 study. *Study Health Technol. Inform.*, 2012, **176**, 117–121.
10. Hong, Y., Wong, A. S. and Robinson, P. D., Effects of load carriage on heart rate, blood pressure and energy expenditure in children. *Ergonomics*, 2000, **43**, 717–727.
11. Pascoe, D., Pascoe, D. E., Wang, Y. T., Shim, D. M. and Kim, C. K., Influence of carrying book bags on gait cycle and posture of youths. *Ergonomics*, 1997, **40**, 631–641.
12. Ramaprasad, M., Allias, J. and Raghuveer, A. K., Effect of backpack weight on postural angles in preadolescent children. *Indian J. Paediatr.*, 2009, **47**, 575–580.
13. Motmans, R. R. and Tomlow, S., Trunk muscle activity in different modes of carrying schoolbags. *Ergonomics*, 2006, **49**, 127–138.
14. Attwells, R. L., Birell, S. A., Hooper, R. H. and Mansfield, N. J., Influence of carrying heavy loads on soldier's posture, movements and gait. *Ergonomics*, 2006, **49**, 1527–1537.
15. Hong, Y. and Cheung, C. K., Gait and posture responses to backpack load during level walking in children. *Gait Posture*, 2003, **17**, 28–33.
16. Majumdar, D., Pal, M. S. and Majumdar, D., Effects of military load carriage on kinematics of gait. *Ergonomics*, 2010, **53**, 782–791.
17. Singh, T. and Koh, M., Effects of backpack load position on spatiotemporal parameters and trunk forward lean. *Gait Posture*, 2009, **29**, 49–53.
18. Bobet, J. and Norman, R. W., Effects of load placement on back muscle activity in load carriage. *Eur. J. Appl. Physiol.*, 1984, **53**, 71–75.
19. Connolly, B. H., Cook, B., Hunter, S., Laughter, M., Mills, A. and Nordtvedt, N., Effects of backpack carriage on gait parameters in children. *Pediatr. Phys. Ther.*, 2008, **20**, 347–355.
20. Kim, S., Ergonomic analysis of army backpack designs: back and shoulder stresses and their implications. A dissertation submitted to the faculty of The University of Utah.
21. Puckree, T., Silal, S. P. and Lin, J., School bag carriage and pain in school children. *Disabil. Rehabil.*, 2004, **26**, 54–59.

22. Rateau, M. R., Use of backpacks in children and adolescents: a potential contributor to back pain. *Orthopaedic Nursing*, 2004, **23**, 101–105.
23. Temple, J. R., Paul, J. A., Van den Berg, P., Le, V. D., McElhany, A. and Temple, B. W., Teen sexting and its association with sexual behaviors. *Arch. Pediatr. Adolesc. Med.*, 2012, **166**, 828–833.
24. Voll, H. J. and Klimt, F., Strain in children caused by carrying school bags. *Offentl Gesundh Wes.*, 1977, **39**, 369–378.
25. Negrini, S. and Carabalona, R., Backpacks on! Schoolchildren's perceptions of load, associations with back pain and factors determining the load. *Spine*, 2002, **27**, 187–195.
26. Watson, K. D., Papageorgiou, A. C., Jones, G. T., Taylor, S., Symmons, D. P., Silman, A. J. and Macfarlane, G. J., Low back pain in schoolchildren: occurrence and characteristics. *Pain*, 2002, **97**, 87–92.
27. Abe, D., Muraki, S. and Yasukouchi, A., Ergonomic effects of load carriage on energy cost of gradient walking. *Appl. Ergon.*, 2008, **39**, 144–149.
28. Hsiang, S. M. and Chang, C., The effect of gait speed and load carrying on the reliability of ground reaction forces. *Saf. Sci.*, 2002, **40**, 639–657.
29. Kinoshita, H., Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait. *Ergonomics*, 1985, **28**, 1347–136.
30. Legg, S. J. and Mahanty, A., Comparison of five modes of carrying a load close to the trunk. *Ergonomics*, 1985, **28**, 1653–1660.
31. AARN Bodypacks; http://www.aarnpacks.com/
32. Ramadan, M. Z. and Al-Shayea, A. M., A modified backpack design for male school children. *Int. J. Ind. Ergon.*, 2013, **43**, 462–471.
33. Lloyd, R. and Cooke, C., Biomechanical differences associated with two different load carriage systems and their relationship to economy. *Human Movement*, 2011, **12**, 65–74.
34. Chow, D. H. K., Kwok, M. L. Y., AuYang, A. C. K., Holmesa, A. D., Cheng, J., C. Y., Yao, F. Y. D. and Wong, M. S., The effect of load carriage on the gait of girls with adolescent idiopathic scoliosis and normal controls. *Med. Eng. Phys.*, 2007, **28**, 430–437.
35. Cassidy, D., Healey, E., Kocienski, K. and Pulver, B., Improved backpacking load carriage system. Major qualifying project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of requirements for the Degree of Bachelor Science, 2017.
36. Kirk, J. and Schneider, A. D., Physiological and perceptual responses to load-carrying in female subjects using internal and external frame backpacks. *Ergonomics*, 1992, **35**, 445–455.
37. Novak, J. S., Posture, get it straight! New York, Perigee Books; 1st edn, 1999.
38. Kistner, F., Fiebert, I., Roach, K. and Moore, J., Postural compensations and subjective complaints due to backpack loads and wear time in school children. *Pediatr. Phys. Ther.*, 2013, **25**, 15–24.
39. Katarzyna, W. C., Renata, S. I., Maciej, R. and Aleksandra, T., Influence of the weight of a school backpack on spinal curvature in the sagittal plane of seven-year-old children. *BioMed Res. Int.*, 2015, **15**, 1–6.
40. Rodríguez, S. A. E., Jaworski, R., Jensen, A., Niederberger, B., Hargens, A. R. and Frank, L. R., Effect of load carriage on lumbar spine kinematics. *Spine*, 2013, **38**, 783–791.
41. Al-Khabbaz, Y. S. S. M., Shimada, T. and Hasegawa, M., The effect of backpack heaviness on trunk-lower extremity muscle activities and trunk posture. *Gait Posture*, 2008, **28**, 297–302.

ACKNOWLEDGEMENTS. The study was granted by the National Project Implementation Unit, Noida, India. The authors thank the management committees of schools especially the parents and students. The authors also thank, PGIMER Chandigarh for their valuable feedback.

Received 31 October 2017; revised accepted 22 May 2018

doi: 10.18520/cs/v115/i5/930-936

Obtaining 3D and 3D revert cultures of BMG-1 cell line for the analysis of cytokine expression differences

Maddaly Ravi* and Aishwarya Subramaniyan

Department of Human Genetics, Faculty of Biomedical Sciences, Technology and Research, Sri Ramachandra University, Porur, Chennai 600 116. India

Methods to utilize cell lines as research material are evolving continuously as with the parallel advancement in instrumentation and analysis technologies. One such advancement in culture methodology of particular significance is the 3-dimensional (3D) way of culturing cells. It is now clear that 3D cultured cells behave differently from their monolayer (2D) counterparts and provide meaningful insights into complex cellular mechanisms that are rather difficult to study using 2D cultured cells. We take a step further and describe 3D-reverts, an extension of the '2D to 3D' culture methodology. We demonstrate that 2D, 3D and 3DRs express cytokines differently and also that such differences extend to the culture stages of 3D and 3DRs, in a time-dependent manner. This approach of analysing differences between 3D and 3DRs as a time-dependent or culture stage-dependent manner will surely enhance the utility of cells that will augment the 3D culture systems.

Keywords: Agarose hydrogels, BMG-1, 3D aggregates, 3D reverts, cytokines; differential expression.

CYTOKINES are mediators for several functions including those involved in complex immunological mechanisms as associated with several cell types. The functions of these mediators are even more significant in conditions such as cancers. Several networks of cytokines are known to be associated with specific cancer types, apart from a few individual ones that mediate specific functions in cancers[1,2].

The utility of cancer cell lines as material for cancer research has been greatly enhanced by culturing them as 3D aggregates/spheroids/tumeroids. This approach has resulted in obtaining meaningful results from the cultures and can be more relevant to a realistic *in vivo* condition[3,4]. We have taken a step further and looked into 3D reverts (3DRs) for their utility in cancer research. Such reverts can be obtained by reintroducing 3D cultures into culture units sans matrices or scaffolds. We feel that these reverts behave differently compared to their 2D and 3D counterparts whose analysis can provide insights into the complex mechanisms of cancer cell biology with a better resolution. In this study, we use BMG-1 (human malignant glioma) cell line to demonstrate that

*For correspondence. (e-mail: mravi@sriramachandra.edu.in)