Original Article

A Case Study on Biomechanical Analysis of Kneeling and Squatting Methods while Manual Lifting Using Motion Capture Analysis

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ABSTRACT: *Weight lifting techniques had been long discussed and debated between squatting and semi-squatting (kneeling) techniques. Using motion analysis and force plates, the weight lifting tasks were measured for comparison. Participant was required to lift different weights of 5kg, 10kg and 15kg using squat and semi-squat techniques. The tasks were randomized and the performance was measured using Cortex 7.0 and Mokka 6.0. Then kneeling technique was indeed a more efficient and safe posture as compare to the squatting technique that would expose an acute onset of spinal injury. The case study illustrated that kneeling technique was the better technique in protecting the spinal health from any chronic musculoskeletal disorders. Therefore, the study recommended that weight lifting training exercises to be promoted for kneeling postures and provide core muscle in strengthening exercises as an important intervention and training program at workplace.*

Keywords: *Force, Intervertebral Angles, Motion Capture, Technique, Weight Lifting*

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1.0 INTRODUCTION

Supervisors need to be cautious when managing his co- workers' physical activities. Training had always been limited with regards to multitasking. In many instances, proper engineering innovation and controls could not be allocated due to various financial and commitment constraints. Therefore, the cost- efficient control strategies would be adopting hazard isolation and administration control strategies. In the service sector, (e.g.: nurses, stewardess or receptionists) workers would be exposed to various multitasking including lifting objects at various degrees and frequencies in a day. The musculoskeletal system would be chronically affected if the job task required high repetitive movement (even contact stress). Night shifts, improper sleeping posture, inadequate recovery time and poor quality of sleep were all indirectly associated with low back pain with time. Procedures such as venipunctures, dialysis, dressing and nursing care were commonly done under non-ergonomic conditions (Theodora et al., 2010).

Papi et al. (2017) and Tam et al. (2019) correctly pointed out that there were ergonomic and psychological factors related to low back pain especially at work. Numerous efforts have been spent on developing tools to prevent chronic back pain, which include questionnaires (Traeger et al., 2014) and simple field- assessments especially addressing sports related injuries. Surprisingly, objective and standardized anthropometric and ergonomic assessments at workplace settings were not easy to come by. Most physical assessment of the human body catered for human efficiency enhancement for development of sports. Studies have shown that the intervertebral discs of running athletes were reported to be healthier than individuals who were not active in sports (Belavy et al., 2017) while Yoo & An (2009) correlated musculoskeletal pain with poor physical posture. Therefore, the human posture and anthropometric knowledge could answer the chronic presentations of musculoskeletal diseases.

Other sports that emphasized on the technique would be the weight lifting category. Weight lifting techniques were catered for competitive performances and prevention of long-term injuries and disabilities. It would be interesting to assess the movement of the human body when challenge with weight lifting under working environment or requirements. Pourahmadi et al. (2019) concluded that kinematic/ motion analyses were very different assessments that medical science assessments and that there were not many motions analysis reviews (even assessments among healthy population were limited) in the literature. Meanwhile, Yamamoto et al. (2017) and van der Have et al. (2019) mentioned of low back pain association with forward bending or stooping posture movements. Besides the movement and forces, the angle movement could also be observed using the motion analysis (Suter et al., 2019); squatting compared with kneeling (semi-squat) techniques. Nevertheless, there are limited documented visuals or figures on how the vertebrae, typically the lumbar angles changes and its relationship to low back exposures pain while lifting in squatting versus kneeling (semi-squatting) positions.

This case study aims to present the relationship of forces created via different lifting postures (kneeling versus squat postures) while lifting various different weights from the ground to the standing posture. The study would identify the movement of the thoracolumbar spine (thoracic kyphosis) and lumbosacral spine (lumbar lordosis) with the spinal angle changes in relation to the forces during lifting. By comparing the two postures, the benefits and limitations on the two lifting postures can provide preventive knowledge for ergonomic health purposes.

2.0 METHOD

This study was approved by the Ethics Committee of the Faculty of Design at Kyushu University, Japan. A male participant (35 years old, 178cm, 78.3kg and BMI of 24.62kgm^{-2}) had volunteered and consented to participate in this study. The participant's kinematic data were collected using a 3D motion- capture system (Cortex 7.0; Motion Analysis Corporation, Santa Rosa, CA, USA) while two force platforms (9286A; Kistler, Winterthur, Switzerland) were sampled at 1000 Hz in sync with the kinematic data through the 3D motion- capture systems. There were 11 infrareds high- speed cameras that would be recording movements with a sampling rate of 120 Hz.

The task conditions were box lifting at weight 5kg, 10kg, and 15kg with kneeling or squatting method in randomized order. The weight was based from the Ergonomic Risk Assessment at Workplace 2017 of Malaysia (DOSH, 2017). Subsequently, the participant was asked to rate his perceived exertion based on the Borg's Rating of Perceived Exertion (RPE) scale (Borg, 1990) after every trial. The kneeling method in this study refers to a singular kneeling of either side of the human body while the task was randomized as with the weighs mentioned above and as shown in Fig. 1. The squatting method was referred as crouch posture with his knees bent and the heels were adjacent to the hamstring muscles. At force plates, the measured forces were identified as X (left to right), Y (back to forward) and Z (top to bottom) vectors. Finally, the total resultant forces (in Newton- N) were used in this report.

A total 22 reflective markers were placed on the participant's body surfaces to collect the kinematic data; from the anterior trageus, distal acronium process to the 5th little toe, 8 markers over the box and 8 markers were placed on the two tables placed above one another. Each dot on Fig. 1 represents the refractory markers. Before the initiation of the study, the participant was allowed to change and prepare himself. Pre-assessment medical screening such as weight and height was also taken. The 22 markers were placed on the anatomical surfaces of the important structures of the body off-lined and the movements of the markers were recorded and calculated by the Cortex 7.0. The participant was told to begin the trial by standing at rest. Then, the participant would have to pick up the weighted box and finally to stand straight (Fig. 1) with the weighted box either using kneeling or squatting according to the randomized protocol. The task conditions (two postures and three weights) were randomized for the participant, and each condition was repeated for three repetitions. Randomization is needed to prevent the participants to be able to prepare himself on the various different trials that would need to be performed.

A single task would take 30 seconds (maximum). In between each task, the participant was allowed 60 seconds of recovery time. The entire motion capture would require approximately an hour to complete. For the purpose of the study, the focus was on the spinal movements of C7, T6, T12, L5 and S1 vertebraes in relation to each other as they move on their respective vertebral planes. The lumbar lordosis angle was calculated from the thoracolumbar and thoracosacral segments. The thoracic kyphosis angle was calculated from the upper thoracic segments (the C7-T6-T12 vertebral angle changes) and the lumbosacral segments (the T12-L5-S1 vertebral angle changes) were also measured. For each task, the participant would have to repeat the task 3 times. All the randomization effect, data, weight, movement, graphic videos and forces produced and captured by the cameras and force plates were recorded into the Cortex 7.0 software.

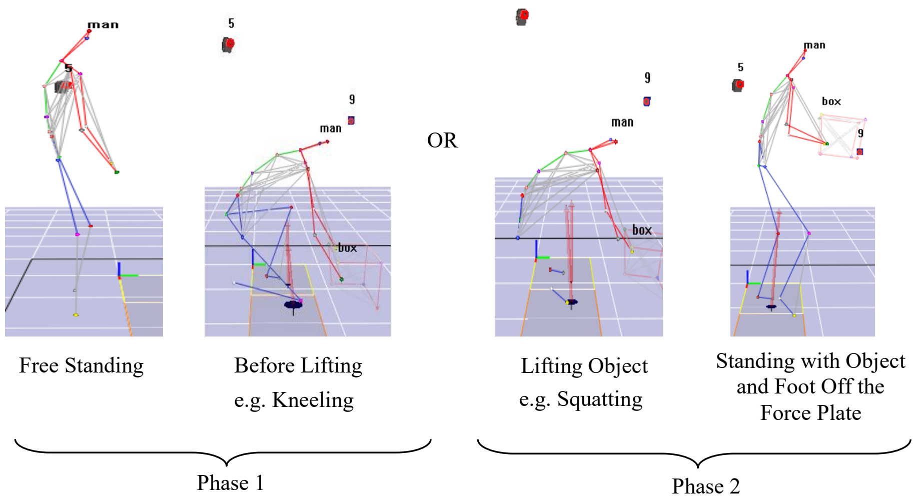


Figure 1 Difference Postures and Phases during Lifting

In this case study, the single lifting motion cycle was divided into Stand to Lift (Phase 1) and Box Lifting (Phase 2) (Fig. 1). The measured forces were identified as X (left to right), Y (back to forward) and Z (top to bottom) vectors. Lastly, the total resultant forces were used in this report. The maximal forces produced over the left foot during the movements were recorded as the right knee would be used during the kneeling posture that would be less consistent compared to the left foot. The Borg's RPE was also obtained from the participant after each task was performed. Besides the experimental movement of the tasks that were captured, the changes in the management of the thoracic and the lumbar curvatures were also observed and measured. Finally, the reporting method of Institute of Biomechanic Standards were used as reference (Wu et al., 2005 and Hasegawa et al., 2018) when the angle changes were recorded by the Cortex 7.0 and Mokka 6.0 system.

3.0 RESULTS & DISCUSSIONS

Fig. 2 showed the difference values of the Borg's Rapid Perceived Exertion (RPE) between kneeling (semi-squatting) and squatting postures with increased weight. Using Borg's RPE, we could conclude that the tasks were not too physically strenuous and should not increase the cardiovascular demand (Max RPE: 6 units) on both occasions. Findings suggested that the participant felt less amount of effort was needed when lifting objects above 10kg when kneeling as compared to squatting postures. Although very efficient, the squatting technique did increase perceived exertion to the participant as compared to kneeling technique.

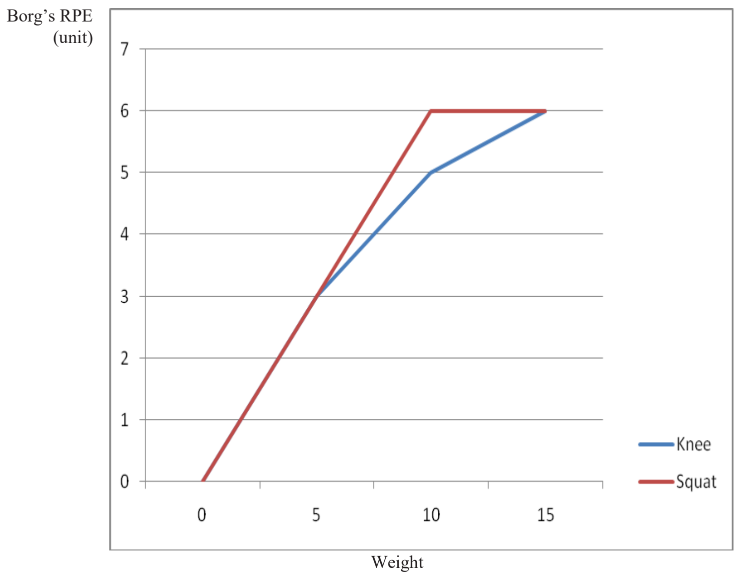
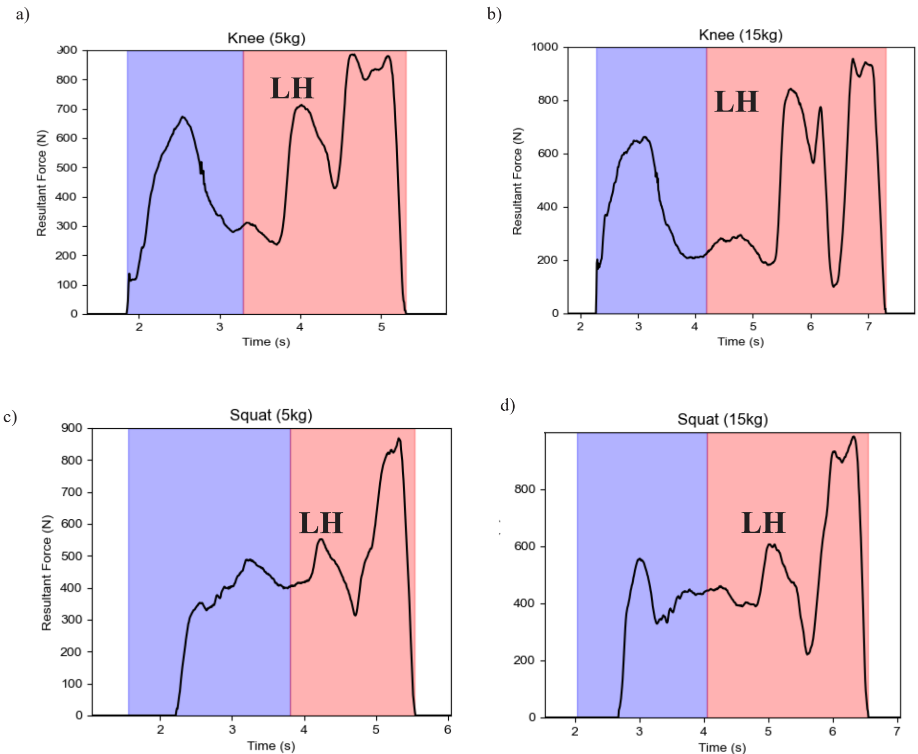


Figure 2 Documented RPE when Kneeling or Squatting

However, the study managed to record higher forces that were generated when the participant was adopting the squatting technique as compared to kneeling technique to lift the similar 5kg and 15kg from the ground (Fig. 3). Phase 1 (Blue Segment) referred to the participant standing to box lifting position. In phase 1, the participant would need to bend his body and move nearer to the box. Phase 2 (Red Segment) referred to the position from lifting the box to standing position with more movement and force generated. The squatting technique produced a localised movement force (Fm) as compared to the kneeling techniques (Lifting hump-LH). The squatting technique would expose a smaller number of muscles in a short period of time as compared to the kneeling technique. Therefore, the intensity of the ergonomic risk would be much higher in the squatting technique as compared to kneeling technique. The kneeling posture with 15kg object was noted to be using larger number of muscles of the body as they body adjust, prepare and accommodate to the increased physical activity that needed to be performed. With additional energy or force generated, the angle range on both kneeling and squatting was relatively similar.



LH- Lifting Hump

a) Kneeling Posture with 5kg box
b) Kneeling Posture with 15kg box
c) Squatting Posture with 5kg box
d) Squatting Posture with 15kg box.

Figure 3 Forces Generated with Various Posture and Weighted Box

Table 1 Resultant Force Measured

Level	Rest	Standing with empty box (95% CI)	Standing with box plus 5kg (95%CI)	Standing with box plus 10kg (95%CI)	Standing with box plus 15kg (95%CI)
Force (N)	781.02 ±7.37	808.31 (805.53 to 811.10)	853.43 (849.95 to 856.91)	877.50 (874.71 to 877.52)	927.93 (923.78 to 930.03)

Table 2 Maximal Forces during Lifting Objects from Floor

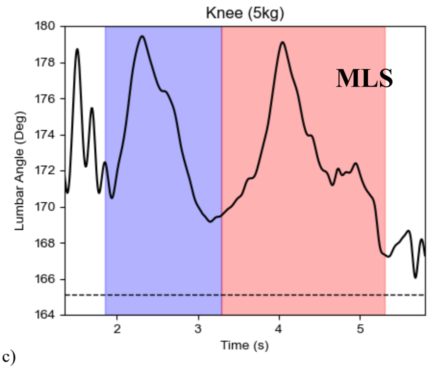
Weight (kg)	Stand-to-Lift (Phase 1)		Box Lifting (Phase 2)	
	Knee	Squat	Knee	Squat
5	665.57 ± 26.59	510.17 ± 71.0	878.84 ± 14.42	862.64 ± 5.53
10	662.03 ± 14.05	521.66 ± 75.40	869.17 ± 48.10	918.00 ± 6.24
15	672.60 ± 9.15	522.39 ± 38.61	955.60 ± 0.85	959.31 ± 22.32

Table 3 Angle Changes from Neutral Positions

Weight	Posture	Stand to Lift (Phase 1)		Box Lifting (Phase 2)	
		Thoracic	Lumbar	Thoracic	Lumbar
5kg	Knee	4.57 ± 0.96	14.72 ± 0.07	4.01 ± 0.48	14.04 ± 0.51
	Squat	10.70 ± 1.10	12.95 ± 0.22	6.89 ± 0.91	13.34 ± 0.44
10kg	Knee	6.47 ± 2.19	13.67 ± 0.19	5.33 ± 2.31	13.46 ± 0.13
	Squat	7.62 ± 0.93	14.37 ± 0.41	6.44 ± 0.77	13.90 ± 0.36
15kg	Knee	8.29 ± 1.00	14.16 ± 0.32	8.31 ± 1.30	14.39 ± 0.37
	Squat	10.70 ± 6.81	13.00 ± 1.29	6.89 ± 0.38	13.34 ± 0.38

The results are presented in mean±SD, unless otherwise specified. Table 1 showed the resultant forces at rest from no object to exposure when lifting objects with 15kg. During the participant's movement from standing to kneeling or squatting to pick up the object that was on the floor, the force plates recorded forces that were changing during movements (Table 2). Table 3 illustrated the forces that were documented during the initiation stages as the participant kneeled or squatted to lift an object during Phase 1 to Phase 2. The forces along with the movements were dynamic and similar forces were generated between both postures in Phase 2.

a)



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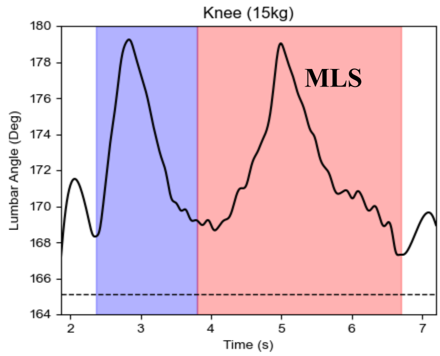

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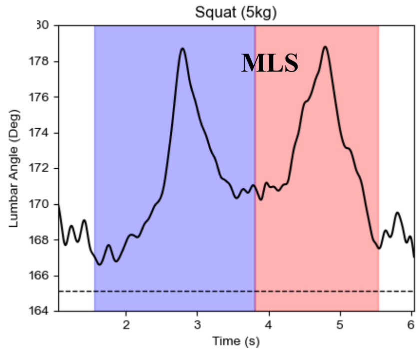

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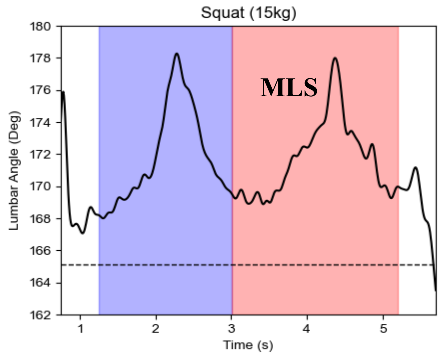

MLS- Maximal Lumbar Stability

a) Kneeling Posture with 5kg box
b) Kneeling Posture with 15kg box
c) Squatting Posture with 5kg box
d) Squatting Posture with 15kg box.

Figure 4 Lumbar Angle Changes

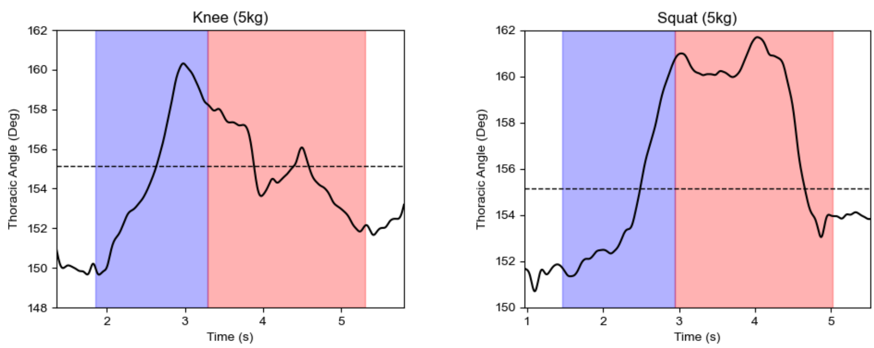

Figure 5 Thoracic Angles Lifting 5kg Objects (Kneeling and Squatting Postures)

However, the squatting technique exhibited relatively erratic and unstable angle movements to recovery as compared to kneeling technique (Fig. 4). In fact, the squatting technique transfers some of the physical force to the upper back (thoracic region) as the body entered Phase 2. Such thoracic angles were relatively protected when using the kneeling technique as compared to the squatting technique (Fig. 5). Therefore, there would be stronger and forceful impact of the vertebral during the squatting technique as compared to kneeling technique even at 5kg.

Fig. 4 illustrated in detail the different physical (muscle) hazards that the body was exposed when different techniques were used. As similar angles were required, the final postures of lifting were similar (Maximal Lumbar Stability- MLS). Our motion findings were consistent with van der Have et al. (2019). The kneeling technique provided a much stable and gradual spinal angle changes. Once MLS was achieved, the core muscles would enter the predominant isometric phase which would allow the lumbar spine to return to its anatomical angle to reduce injury.

There were several advantages in using motion capture to document spinal movements during object lifting. Although, motion capture along with force plates would be able to document movements and the forces that interplay during the physical activities, it should be important to note that other modalities could be added or incorporate to increase the precision and to detail out other important parameters such as muscle contractility, muscle strength, oxygen- ventilation perfusion, neural impulses, spinal kinematics (Papi et al., 2017) and many others anthropometric assessments. This study was designed to document inter-vertebral movements during object lifting. With surface markers, the angle movements of the vital skeletal and muscle points were objectively reported and represented (Stinton, 2011).

From literatures, kneeling technique was ergonomically efficient and would prevent back injuries (Vecchio, 2017), but relatively less power. Both techniques had similar loss of lumbar lordosis giving added pressure and compression to the disc. However, the stability of the kneeling posture was affected when the objects were 15kg. Our findings were consistent with Wang et al. (2012). Without adequate recovery and rest, chronic fatigue would further injure the affected workers (Vecchio 2017 and Patel 2020). Therefore, untrained or unprepared workers should be allowed to decline such tasks if the activity was done without supervision by a trained senior colleague or health professionals (e.g., fitness trainer or physiotherapists). In the study, the untrained participant had consistently described difficulty in lifting objects via squatting compared to kneeling (semi-squat) technique. As a case study, this participant was a healthy, a 30-year-old Asian male that reported healthy lumbosacral or lumbar lordosis angles. The participant was a teaching staff of the university as all students in Japan was told to return home due to the Covid-19 pandemic. It was intended to have more than 20 participants form the university (majority Asians) to participate in this study. With large number of participants and data, we could compare and measure the range of muscle movement among the individuals. Therefore, the level of Asian referential and representation of this study is limited.

The lumbar angle changes increased with additional weight during both squatting and semi- squatting (kneeling) techniques. Caglayan et al. (2014) managed to report that an increased lumbar lordosis angle was associated with onset of low back pain. A key important discussion that squatting lifts (trained appropriately especially in sport performance) generate more efficient and effective competitive heavy lifting, particularly with a straightened back and training (Wang et al., 2012, Kim 2014 and Cho et al., 2017). The motion capture had successfully provided that insight and would recommend the importance of training and physiotherapy and core exercises for workers to build a strong back.

Postures of lifting in competitive weight lifting sports applied weights to be supported on shoulders/ upper trunk in order to exceed daily lifting capacity (Myer et al., 2014 and Kushner et al., 2015). Although acceptable and practiced in the past among sea-farers unloading shipments at seaports or docks, these techniques had not been commonly used in this modern era. Kneeling technique would be a rather appropriate and safer technique of lifting objects less than 10kg. Even procured tools to assist lifting had to be introduced and taught to all workers effectively, especially in the service industries like banking, corporate business and the healthcare industry. Secondly, perhaps a paradigm shifts especially for nursing staff or discipline to incorporate a healthier practice to work on standing computer designs along with serving of medication and attending to patients. This would allow nurses to really enjoy their rest and breaks sitting down as compared to repetitive or prolonged sitting with limited movement which would be less healthy to the human body.

As recommendation, this study proposes the need for employers to designate dedicated trained personnel to be in- charge of the back care treatments aimed to prevent musculoskeletal injuries with proper lifting technique training, nutrition and medical care to strengthen the back muscles typically the multifidus muscle. Interestingly, most literatures suggested that body- building squatting exercises were good core exercises to strengthen the back structures (Al-Otaibi, 2015, Cho et al., 2017 and Lorenzetti et al., 2018). The multifidus muscle thickness was noted to have a very close relationship with low back pain (Wallwork et al., 2009). 'BackCare' in the form of preventive back strengthening programmes and workplace ergonomic investments would delay or prevent an early onset of degenerative changes to the spine of all workers at work. Medical screening recommendation such as the Unilateral Hip Bridge Endurance Test (UHBET) would be a good physical assessment of the strength a worker's core muscles (Butowicz et al., 2016). The idea would be to prevent occurrence of micro-injuries over the vertebral disc that would be dehydrated and replaced by fibrous tissues (Ract et al., 2015). Such un-prevented pathogenesis would promote back pain and prolapsed or herniated intervertebral discs. As such, core muscle strengthening and squatting exercises (Lorenzetti et al., 2018) would improve performance and reduce dependency on the spine/ back to lift objects from the ground (Patel, 2020).

Besides that, this study also proposes that employers from all sectors to designate a 'Team Lifting' personnel who has knowledge in ergonomics awareness and weight lifting training at work particularly in the service and administrative industries (Theodora et al., 2010). These individuals should be upskilled further with the knowledge on muscle strengthening and fitness benefits, covered in the scheduled nutritionist and physiotherapist sessions. Our study clearly showed that structured physical training activities would be required to be implemented for manufacturing workers or industries that involved extensive manual lifting work (Cho et al., 2017 and Patel, 2020).

However, there are limitations in this study. While testing out the kneeling posture, the knee was used to balance the human body to lift the box. Therefore, the recording or motion captured between the lower limbs were relatively inconsistent. Although the systemic bias had been addressed, the quality of knee posture information would be limited as compared to the squat posture data. On the other hand, the participant successfully demonstrated that the squat technique provided a powerful and sustained force during lifting (Fig. 3). It is advised that it would be important to maintain a straight posture of the back to prevent possible injuries during the squat posture (Kim, 2014).

At the muscle level, Hemming et al. (2018) studied the kinematics movement of the spine among individuals with non- specific chronic low back pain. These people specifically had more markers (13 markers) along the spine as compared to our study (6 markers). As the spine moved, the spinal changes involved flexion and all active extension pattern motor control impairment should be captured accurately. The benefits of this study would be enhanced further with a larger recruitment of participants in safer conditions, post pandemic.

5.0 CONCLUSION

Both techniques of kneeling and squatting while lifting had different advantages with regards to lifting the objects. Lifting heavy objects using the kneeling technique may have illustrated lower ergonomic risk as compared to the squatting technique. Based on the law of energy conversion, additional pressure/ force would receive or be absorbed by the joints, discs and soft tissues of the human body during the squatting technique. Although the squatting technique could achieve a lifting task faster and easier, the squatting could promote more micro- injuries to the spine as compared to the kneeling technique. Therefore, all manual workers and relevant stakeholders need to be trained with Back Care awareness and prevention programme to prevent prolapsed intervertebral disc at work.

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