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Analysis on Biomechanical Differences Depending on Changes in Postures during Farm Work

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Objective: This study looks into biomechanical variables occurring when one moves in a sitting posture, and presents objective references to make improvements in work environments of farm workers.

Background: The farmers have more common musculoskeletal disorders compared to other professions, because they are much more exposed to biomechanical risk factors. The sitting posture that is the representative form of the squatted, can cause typical knee joint diseases, such as osteoarthritis or patellofemoral pain syndrome of the knee joint. Therefore, a quantitative study of knee load upon the movement in a squatting posture is required.

Method: In order to proceed with its investigation, the study examined movements in a sitting posture with and without a lower body supporter through a three-dimensional image analysis and by using Surface EMG. The study compared and analyzed the average muscle activity and the maximum muscle activity as well.

Results: Every movement in a sitting posture is related to loads onto the knee joints and, when the farm workers move to sides, the study observed a high level of bowlegged moment. The study also noticed differences in muscle activity of medial gastrocnemius with and without the lower body supporter.

Conclusion and Application: The study argues that what has been discussed so far is evidence to prove how the farm working environments should be improved in consideration of these movements observed when the farm workers move in a sitting posture.

Keywords: Squatting, EMG, Knee moment, Lower extremity supporter

1. Introduction

Crops can be classified into rice, greenhouse crops, open field crops, fruits and livestock farming by agricultural type in Korea, and they show a characteristic that different diseases associated with hazardous factors occur according to crop. Especially, open field crops or greenhouse crops grow in the low surface places, and therefore most farm workers work in back-bending, squatting or kneeling postures. According to the survey of diseases and injuries associated with farm work of farm workers in 2012, musculoskeletal disorders took up very high ratio at 92.5% among farm workers' farming-related diseases. The major causes of musculoskeletal disorders associated with farm work diseases are reported to be focused on back (50.6%) and knees

(31.6%) (RDA, 2015).

The squatting posture or kneeling posture increases patellofemoral joint pressures, causes the transformation of knee joint cartilage, and induces knee osteoarthritis. Female farmers mostly carry out farm work in relation with Korean field crops, which implies that far higher knee osteoarthritis can occur to female farmers than male farmers (Kim et al., 2010).

Momentary biomechanical load of work in squatting or kneeling posture is not bigger than weight handling work. However, if a person works in a squatting posture for more than two hours a day, 2.77 times higher load is given to knee joint than the work of less than two hours a day (Kim and Ryu, 2005), and joint pressure also increases 7.8 times more than working in a standing position (Kim and Jang, 2008). Continuous farm work in such unstable postures is reported to be the cause of representative knee joint diseases such as degenerative arthritis and patellofemoral pain syndrome (Lee et al., 2002). For such a reason, squatting posture is classified as a major risk cause of musculoskeletal disorders in the U.S (NIOSH, 1981).

Upon looking at studies related work-related joint diseases, studies subjectively evaluating discomfort in specific postures and various studies applying quantitative methods through simulation have been carried out (Lee et al., 2002; Burgess, 2003; Straker, 2003; Jung and Jung, 2005). According to the results of those studies, discomfort increases, because major muscles should be contracted and mobilized in a knee-bending posture. Although using knees in a lifting posture can protect one's back, which was reported to be knee burdening work. Even though knee load is unavoidable in a squatting posture, it is reported that some load can be reduced through a lower body (extremity) supporter. Those studies were conducted in the static postures, and therefore studies considering movements occurring in actual farming sites need to be performed.

The quantitative analysis taking into account mobility in a squatting posture is judged to be very important in a study associated with work-related knee joint diseases. As the height of a lower extremity supporter is higher in movement with a squatting posture presented in a previous study (Lee et al., 2011), it was reported that the muscle activity of rectus femoris extending a knee increases due to such a movement. Therefore a quantitative study on differences according to the status of wearing a lower extremity supporter is required.

This study examines what effects of a squatting posture and the wearing of a lower extremity supporter in the farm work for open field crops and greenhouse crops have on muscle activities and knee joint moment. To this end, this study comparatively analyzed the kinetic variables function to lower limb joints and muscle activity level according to the wearing/non-wearing of a lower extremity supporter in relation with front squatting squatted movement and side squatting movement with high occurrence frequency in the farm work through the quantification of the variables and the level.

2. Method

2.1 Subjects

This study selected six female adults, who understood the study purpose sufficiently and revealed their intention to participate in the experiment voluntarily, as the study subjects. The subjects participating in the experiment had no musculoskeletal disorders in the past and at present, and can act normally without any experience of treatment for pain associated with musculoskeletal system within recent six months. Table 1 shows the physical characteristics of the participants in the experiment.

2.2 Experimental equipment

The experiment was performed in a kinetic lab of C University. Measurement was conducted in a sampling speed of 1,000Hz/s

Table 1. Characteristics of subject

Age (years old)	Height (cm)	Weight (kg)	Length of leg (cm)	Knee height (cm)
22.5 (±SD:0.5)	155.4 (±SD:2.7)	53.5 (±SD:3.5)	92.7 (±SD:1.9)	43.3 (±SD:1.4)

*SD: Standard Deviation

using a ground reaction force gauge (AMTI ORG-6, USA) and data were collected through the Kwon 3D XP (Visol, Korea) using six infrared cameras. To analyze lower limb muscle activity level, measurements were made by sampling eight-channel wireless Noraxon (Noraxon Myorearch, USA) with 1,000Hz. Images, ground reaction force and electromyogram (EMG) signal synchronization were synchronized with LED and ground reaction force sync channel using a sync system box (VSAD-101USB, Visol, Korea). EMG signal was synchronized by generating transistor & transistor logic (TTL) signal, when the sync button is pressed through setting up the last channel as the sync channel.

2.3 Experimental design

As for the lower extremity supporter, a lower extremity supporter, distributed in markets, with 11cm in height enabling to take a stable posture in which the center of gravity is not focused backward was used. (Chung et al., 2003) was selected (Figure 1).

Figure 1. Lower extremity supporter

As for movement, after fixing the lower extremity supporter to contact hips using a waist belt, a front squatting movement (Y-axis: front) and a side squatting movement (X-axis: side) were made (Figure 2 and Table 2).

Before the experiment, the purpose of the experiment was explained to the subjects, and also the experiment method and cautions were conveyed to them. For accurate data acquisition and prevention of unnatural movement, the subjects participated in the experiment, after practicing squatting movement sufficiently. The data of two times of the most natural movements out of the data measured five times repetitively through imaging were analyzed. All the subjects wore spandex sportswear and were shot without wearing shoes. As for the collected data, only left side data were used under the assumption that they become symmetric. To generalize the collected ground reaction force data values, the values were divided by each subject's body weight.

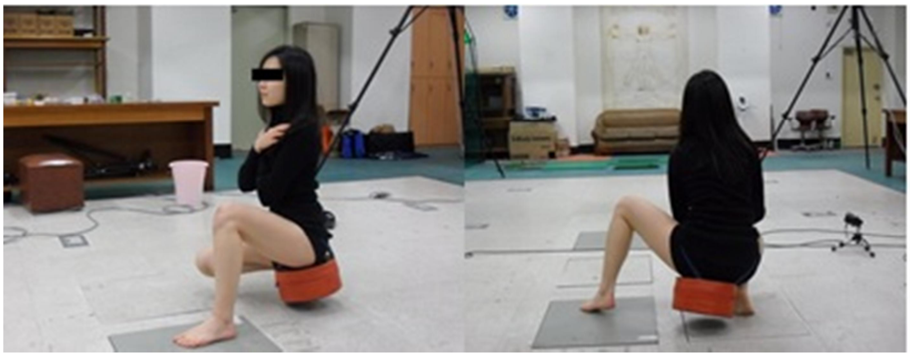


Figure 2. Movement type during the experiment

Table 2. Movement type

Type	Trial	Total
Non-Support Front Movement (NSFM)	sub 6 × trial 2	12
Non-Support Side Movement (NSSM)	sub 6 × trial 2	12
11cm-Support Front Movement (SFM)	sub 6 × trial 2	12
11cm Support Side Movement (SSM)	sub 6 × trial 2	12

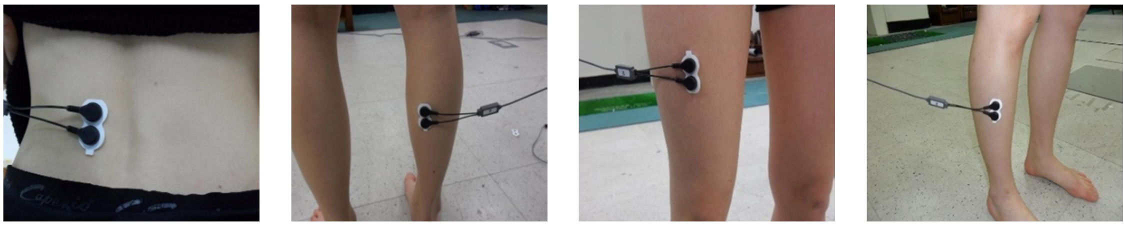
2.4 Measurement of image

Concerning image analysis, 3D coordinates were calculated using the direct linear transformation method (DLT) of Abdel-Aziz and Karara (1971) through making coordinates and the synchronization of control points and human body joints' mid-points. To remove noise, smoothing was conducted using a low pass filter method, and interruption frequency was set up as 6Hz. The Kwon 3D XP program was used for data smoothing.

Regarding human body joints, the modeling of ankle joint, knee joint and four segments of foot, shank, thigh and pelvis was performed as rigid body using the anatomical marker information attached to each subject. As for body segment parameters, the data of Plagenhoef et al. (1983) were used. To find each joint's mid-point, the Tylkowsky method (Tylkowski, 1982) was used for hip joint mid-point through the shot images, and the joint mid-points were set up with a mid-point (secondary point) method for knee joint and ankle joint.

2.5 Measurement of ElectroMyoGram (EMG)

For EMG analysis, surface electrodes were attached to the 2cm points to both sides of lumbar spine 4 among the erector spinae (ES), and also to the medial gastrocnemius (MG), rectus femoris (RF) and tibialis anterior (TA) (Cram and Kasman, 1998) (Figure 3). For the EMG analysis, this study processed the raw data acquired through the experiment with rectification and smoothing, and low pass filtering was conducted with 10Hz cutoff frequency. Also, this study calculated maximum EMG and mean EMG according to each subject and each condition in terms of root mean square (RMS) of the processed values.



Erector spinae | Medial gastrocnemius | Rectus femoris | Tibialis anterior

Figure 3. Muscles and position of EMG electrode

2.6 Definition of event

In the experiment in this study, the event and phase setting was classified into the peak of the first vertical ground reaction force (Event 2: E2) and the peak of the second vertical reaction force (Event 3: E3) at the moment in which contacts the ground, based on vertical ground reaction force and image data. This study analyzed by setting up the phase between E1 and E2 as 1 stance phase (1SP), and the phase between E2 and E3 as 2 stance phase (2SP) (Figure 4).

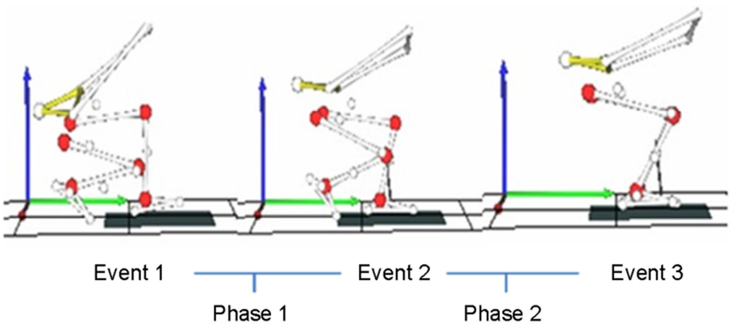


Figure 4. Definition of event and phase

2.7 Data analysis

This study calculated the mean and standard deviation (SD) of knee joint moment and EMG, respectively, in relation with the point in time and phase by each work type. One-way analysis of variance (one-way ANOVA) was performed for differences comparison according to the status of wearing a lower extremity supporter and movement method using the SPSS 20.0. In the significant case, a Scheffe post-hoc test was carried out. This study conducted the test at significance level of α=.05.

3. Results

3.1 Knee joint moment

3.1.1 Flexion/extension moment

Table 3 shows the differences of knee moment of flexion/extension according the status of wearing the lower extremity supporter and movement type.

Table 3. Flexion/extension moment

Event	NSFM (1)	NSSM (2)	SFM (3)	SSM (4)	*F*-value	Post-hoc
Event 1	.050±.204	.024±.131	.135±.241	.087±.097	.661	
Event 2	.937±.269	1.257±.231	.856±.250	.941±.127	5.485**	1,3,4<2
Event 3	.895±.153	.928±.147	.873±.150	.827±.160	1.440	

M ± SD, ** $p < .01$

As shown in Table 3, significant differences were shown in E2 ($p < .01$), and the non-support side movement (NSSM) (side movement without the supporter) showed higher value than other types. Although no significant difference was shown according to movement in E1, SFM showed a relatively higher value. No difference was shown according to movement in E3.

3.1.2 Varus/valgus moment

Table 4 shows the difference of varus/valgus knee moment according to the status of wearing the lower extremity supporter and movement type.

Table 4. Varus/valgus moment

Event	NSFM (1)	NSSM (2)	SFM (3)	SSM (4)	*F*-value	Post-hoc
Event 1	.001±.023	.001±.025	.045±.062	.028±.037	2.621	
Event 2	.088±.058	.250±.112	.118±.057	.205±.078	8.004**	1,3<2,4
Event 3	.115±.058	.156±.048	.143±.049	.147±.068	.889	

M ± SD, ** $p < .01$

As shown in Table 4, a statistically significant difference ($p < .01$) was shown in E2, the peak of the first vertical ground reaction force, and the side movement showed higher value than the front movement, irrelevant of the status of wearing the lower extremity supporter. Although no statistically significant difference was not shown in E1, relatively different values were shown according to the status of wearing the lower extremity supporter, rather than according to movement unlike in E2.

3.2 EMG

3.2.1 EMG of 1 Stance Phase (1SP)

Regarding the mean EMG and maximum EMG of the 1 stance phase (1SP) according to the status of wearing the lower extremity supporter and movement type, statistically significant differences were shown ($p < .05$) in the maximum EMG of elector spinae (ES), as revealed in Table 5. The side movement without the lower extremity supporter showed higher value than the front movement with the lower extremity supporter and the front movement without the supporter. This can be interpreted that higher back flexion movement for 1 stance occurred upon side movement.

3.2.2 EMG of 2 Stance Phase (2SP)

The mean EMG and maximum EMG of 2 stance phase (2SP) from the first vertical ground reaction force peak and the second vertical ground reaction force peak are shown in Table 6.

As shown in Table 6, significant differences were shown in the mean EMG of elector spinae (ES) and the mean EMG and maximum EMG of medial gastrocnemius (MG) (p<.05). Upon specifically looking at these, it can be interpreted that the muscle activity of ES increased upon front movement without the lower extremity supporter to keep body balance with stance leg, and higher mean EMG was shown unlike 1 stance phase (1SP). The mean EMG and maximum EMG of MG showed lower muscle activity in the front movement with the lower extremity supporter (SFM), which can be interpreted that the ankle movement was smaller than other movement types to keep one's balance.

Table 5. 1 stance phase (1SP)

Muscle		NSFM (1)	NSSM (2)	SFM (3)	SSM (4)	*F*-value	Post-hoc
Erector spinae	mean	44.70±10.97	44.70±10.97	44.70±10.97	44.70±10.97	.551	
	max	70.74±17.57	108.47±28.08	84.75±14.87	92.45±13.26	4.607*	1,3<2
Rectus femoris	mean	41.98±21.52	32.85±18.98	49.80±2.44	39.11±14.15	1.482	
	max	84.08±24.41	56.52±27.71	76.75±3.47	78.31±24.85	1.232	
Tibialis anterior	mean	53.47±23.18	25.16±9.51	49.60±24.50	80.35±38.02	1.382	
	max	103.50±37.96	119.44±36.00	87.33±25.41	138.08±50.31	.978	
Medial gastocnemius	mean	41.98±13.32	19.57±7.39	28.83±12.84	21.66±5.82	.656	
	max	78.98±20.47	56.00±31.44	32.51±7.18	51.86±14.61	2.077	

Table 6. 2 stance phase (2SP)

Muscle		NSFM (1)	NSSM (2)	SFM (3)	SSM (4)	*F*-value	Post-hoc
Erector spinae	mean	20.57±5.81	21.95±5.78	28.17±4.54	37.28±13.42	6.124**	1,2,3<4
	max	51.08±15.87	45.37±14.00	41.96±1.18	65.20±15.14	1.971	
Rectus femoris	mean	47.00±19.07	36.18±17.37	47.68±12.09	42.01±16.94	.761	
	max	75.24±29.51	53.90±18.85	56.61±12.96	74.25±39.46	1.319	
Tibialis anterior	mean	82.24±36.60	74.02±29.66	54.98±29.19	88.23±36.74	.660	
	max	130.47±57.11	107.32±52.69	84.06±32.34	139.08±52.36	.977	
Medial gastrocnemius	mean	32.28±8.65	40.25±18.00	7.97±3.77	19.66±7.57	4.256*	3<1,2
	max	58.14±23.25	56.47±25.25	10.71±5.79	33.05±16.03	5.083*	3<1,2

M ± SD, *p<.05, **p<.01

4. Discussion

Overserving the joint moment size upon squatting movement from the biomechanical aspect can help to understand the effects of the impacts depending on movement on knee joint (Lee et al., 2011). Also, the evaluation of various muscles activities intervening each joint movement can be explained in relation with load. This study discusses by setting up squatting posture frequently occurring in the farm work types as the independent variable, and the two biomechanical variables mentioned above as the dependent variable. Before the discussion, this study presents discussion based on biomechanical theory, since such a study has yet to be reported.

Figure 5 shows the changes of flexion/extension moment by event according to each movement.

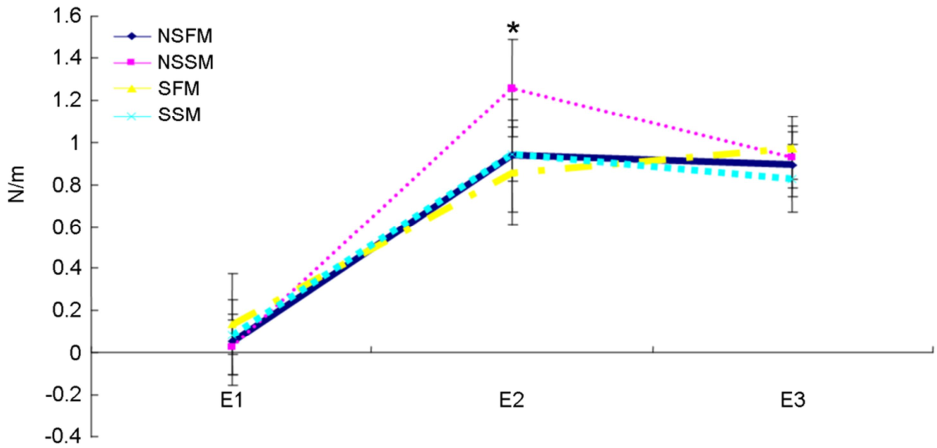


Figure 5. Flexion/extension moment

In the remaining movement types except side movement without the lower extremity supporter (non-support side movement), similar flexion/extension knee joint movement was shown. The side movement without the supporter (NSSM) showed higher extension moment value in E2, which is the highest point in time of supporting foot's vertical ground reaction force in comparison with the remaining movement types.

Such a result means that the up and down movement of gravity center is huge in the process of moving gravity center to foot. The difference with SSM, a similar movement, is considered that movement was small, due to the lower extremity supporter with 11cm in height. Such a discussion was confirmed in the muscle activity difference in the 1SP the reason why the maximum muscle activity of ES in the NSSM showed the highest value is conjected that the muscle activity of ES was shown the highest by extending upper body to make knee joint movement bigger upon side movement. Although the rectus femoris (knee joint extensor muscle) did not show a statistically significant difference, it showed the highest value relatively in the NSSM, which bacs up such a discussion. Therefore, the control of gravity center's up and down movement is considered to be helpful to the momentary extension load of knee joint upon side movement without the lower extremity supporter (non-support side movement: NSSM).

Higher varus movement of knee joint is related with narrow inner joint plane, and can be a cause of PFPS (patellofemoral pain syndrome) in the long-term. The damage mechanism of knee joint meniscus is shown as powerful rotary motion with femoral regions occurring on the horizontal plane in relation with knee joint of flex body weight load. Such a movement, called a close-chain, is shown, when a foot contacts the ground surface, and the squatting movement takes on such a type basically.

Figure 6 shows the change of varus/valgus moment according to each movement.

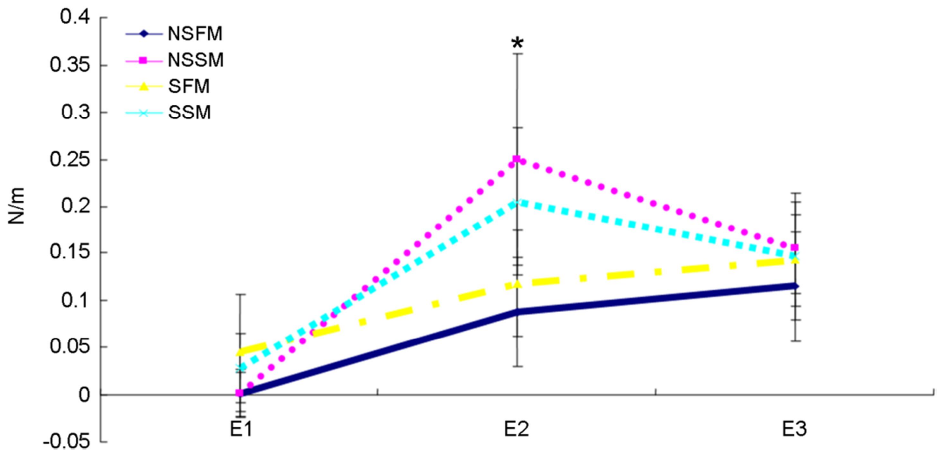


Figure 6. Varus/valgus moment

The side movement without the lower extremity supporter (non-support side movement: NSSM) and the side movement with the lower extremity supporter (11cm-support side movement: SSM) showed bigger change than the front movements with and without the lower extremity supporter (SFM and NSFM) as shown in Figure 6. Such a result means that the varus knee joint revealed in the side movement is bigger, and it can be interpreted that momentary biomechanical load is given on knee joint, not continuous load.

As the flexion of knee joint becomes bigger in general, the rotary motion on the horizontal plane increases, and about 40~50° rotary motion is allowed in the 90° flex knee joint (Neumann, 2004). The rotary motion of knee joint on the horizontal plane changes the varus/valgus moment, and such a mechanism is shown due to the change of knee joint moment arm upon movement. The difference in this study can be interpreted in two ways: First, maximum ground reaction force is revealed in the state that gravity center is not moved to the gravity center axis upon side movement, and with this, the varus moment of knee joint increases. Second, as discussed in the flexion/extension moment above, the varus moment increases, because the moment becomes closer to 90° flexion that can hugely induce rotary motion, since knee joint movement is huge upon squatting movement. Consequently, such two causes increase the varus moment of knee joint, and can be summarized to offer negative cause biomechanically. The side movement in a squatting posture needs to be carefully considered.

Different values according to phase can be a feature in EMG. While statistical differences were shown in the maximum muscle activity from E1, the point in time of foot contacting the ground surface, to E2 in which the first maximum vertical ground reaction force is shown, difference in SSM was shown in 2SP in terms of mean muscle activity. Such a result showed momentary upper body extension movement in 1SP, and is interpreted as showing continuous movement in the upper body extension state in 2SP. The reason why there was a difference between the mean and maximum muscle activities of medial gastrocnemius (MG) in the 2SP is the result of non-activation of plantarflexion upon front movement with the lower extremity supporter. This can be interpreted to show the trend supporting ankle joint in the movement without the lower extremity supporter. The higher flexion of knee joint is conjectured to take a motion to keep one's balance by causing the eccentric muscular contraction of gastrocnemius from the biomechanical aspect.

5. Conclusion

This study was carried out to quantify biomechanical variables and muscle activity level affecting joints according to the status of wearing a lower extremity supporter in relation with front and side squatting movements with high frequency in farm work. As a result, higher knee load was revealed in the side movement without wearing the lower extremity supporter (non-support side movement: NSSM). Through this study, it was confirmed that each dynamic movement in squatting posture is related with the load of knee joint. Especially, high varus moment upon side movement is presented as a cause to arthritis, which is judged to be used as basic data for environment improvement of farm workers. As the experiment in this study was carried out in the environment within a lab, there can be differences from the actual farm work environment slightly. Therefore, there can be some limitations to apply the experiment results by generalizing them. However, the results of this study are conjectured to help relevant studies by quantitatively evaluating knee joint load revealed upon squatting movement.

Acknowledgements

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