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ORIGINAL

Differences in the Joint Movements and Muscle Activities of Novice according to Cycle Pedal Type

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Objective: The purpose of this study was to compare the joint movements and muscle activities of novices according to pedal type (flat, clip, and cleat pedal).

Method: Nine novice male subjects (age: 24.4 ± 1.9 years, height: 1.77 ± 0.05 m, weight: 72.4 ± 7.6 kg, shoe size: 267.20 ± 7.50 mm) participated in 3-minute, 60-rpm cycle pedaling tests with the same load and cadence. Each of the subject's saddle height was determined by the 155° knee flexion angle when the pedal crank was at the 6 o'clock position (25° knee angle method). The muscle activities of the vastus lateralis, tibialis anterior, biceps femoris, and gastrocnemius medialis were compared by using electromyography during 4 pedaling phases (phase 1: 330~30°, phase 2: 30~150°, phase 3: 150~210°, and phase 4: 210~330°).

Results: The knee joint movement (range of motion) and maximum dorsiflexion angle of the ankle joint with the flat pedal were larger than those of the clip and cleat pedals. The maximum plantarflexion timing with the flat and clip pedals was faster than that of the flat pedal. Electromyography revealed that the vastus lateralis muscle activity with the flat pedal was greater than that with the clip and cleat pedals.

Conclusion: With the clip and cleat pedals, the joint movements were limited but the muscle activities were more effective than that with the flat pedal. The novice cannot benefit from the clip and cleat pedals regardless of their pull-up pedaling advantage. Therefore, the novice should perform the skilled pulling-up pedaling exercise in order to benefit from the clip and cleat pedals in terms of pedaling performance.

Keywords: Pedal type, Joint movement, Electromyography

INTRODUCTION

The rapid popularization of cycling has resulted in cycles becoming more than a simple means of transport and now being used for recreation and exercise as well. Consequently, interest in improving pedaling ability and preventing injuries has increased. The number of individuals who have their cycle frames fitted for size or use expensive accessories or equipment to improve pedaling ability and prevent injury has increased not only among elite cyclists but also among untrained individuals. Of the two methods, fitting is the method of adjusting the size and angle of the cycle frame, saddle height, and position of the handles to adjust to the rider's body type and riding style (Bae et al., 2012). This requires the assistance of a trained expert and is not yet widely available in South Korea. The other method of swapping accessories or equipment involves choosing a lightweight frame, adjusting the crankset gear ratio, or selecting a wheel size or pedal type that is better for pedaling. Both methods help to improve pedaling ability and prevent injury. Non-experts and hobbyists tend to prefer selecting and swapping accessories and equipment to fitting because the latter is difficult to find, and the typical accessory that is targeted is the pedals. The pedals are the part that link the rider's body to the cycle and are the element where force is ultimately applied. The force applied to the pedals is transferred to the crankset. As this force overcomes the resistance and inertia of the crankset, it is converted into energy (Raasch et al., 1997). The advantages of the pedals are that they can be easily replaced by anyone and enable pedaling efficiency to be improved at a lower cost than changes to the frame or wheels.

Pedals can be broadly divided into three types. One is the flat pedals. The flat pedal is the standard pedal used in cycles for the general public. As the foot is simply placed on the top of the pedal without any other fixation device, flat pedals have the advantage of being safer than other pedal types. However, the disadvantage of flat pedals is that a pulling force could not be applied after the pedal reaches the bottom dead center (BDC) of the stroke, when it is at its lowest point relative to the crankset. The second type of pedals is the clip pedals (or toe clips). Clip pedals are shaped like a cage that embraces the foot from

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the metatarsals to the tips of the toes. The disadvantages of the clip pedals are that it is awkward to insert and remove the foot from the pedal and that when the foot is fixed with the strap, the foot needs to be detached from the pedal after stopping. On the other hand, the advantage of clip pedals over flat pedals is the ability to apply a pulling force during pedaling. Clip pedals are currently used in track cycling competitions. The third type is the cleat pedals (or clipless pedals), in which the part of the clip pedals that embraces the foot has been eliminated, and the rider wears shoes with cleats on the bottom, which can then be attached to and detached from the pedal. Compared with clip pedals, attachment and detachment are easier for cleat pedals, making them relatively safer. In addition, because the foot is fixed to the pedal as with clip pedals, a pulling force can still be exerted on the pedal. Cleat pedals are considered essential for cross-country, downhill, and road cycling, and use of cleat pedals has been increasing recently not only among elite cyclists but also among non-experts. The disadvantage of cleat pedals is that they require the rider to wear a special shoe with cleats on the bottom.

Hence, several types of pedals have been developed, and physical movements and characteristics differ during pedaling according to the pedal type and the way pedals are connected to the foot. A representative previous study that examined pedaling characteristics according to pedal type measured and compared muscle activities in triathletes who used clip or cleat pedals (Cruz & Bankoff, 2001). The results showed that the use of cleat pedals resulted in decreased activities of the semitendinosus, semimembranosus, biceps femoris, and gastrocnemius lateralis muscles. Several studies have compared pedal types in terms of their effects on muscles in elite athletes, but studies that identified the forces and kinematic forms involved in pedaling with different types of pedals and fixation in non-experts are inadequate. Given that suitable pedal choice improves performance and prevents injuries, the need to identify the muscle activity involved in force generation and movement of the lower body is urgent (Seo et al., 2012). In the case of non-experts, owing to the lack of training in applying a pulling force to the pedals, muscle use and kinematic forms are thought to be similar irrespective of the type of pedal.

Therefore, this study examined the kinematic and muscle activity characteristics in non-experts when pedaling with flat, clip, or cleat pedals, with the aim of providing useful information in choosing the appropriate pedal type for improving performance and preventing musculoskeletal injury.

METHODS

1. Research subjects

The study subjects consisted of 9 healthy novices in their twenties who did not usually participate in cycling, had no musculoskeletal disease, and pedaled normally (age: 24.40 ± 1.90 years, height: 1.77 ± 0.05 m, body weight: 72.20 ± 7.60 kg). All the participants read the explanation of the experiment and signed the consent form prior to participating in the study. The experiment, which adhered to the study plan, was approved by the institutional review board of Konkuk University (7001355-201506-HR-062).

2. Experiment apparatus

All the experiments were performed on a stationary cycle with a roller attached for the subjects to be able to perform identical pedaling on an existing cycle. A three-dimensional (3-D) motion analysis system consisting of 6 infrared cameras (Motion Analysis, USA) and electromyography (EMG; Trigno Wireless EMG Systems, Delsys, USA) were used to measure joint angle, pedal position, and muscle activity. The 3-D motion analysis system and EMG were synchronized, and data were collected at sampling frequencies of 120 and 1,200 Hz, respectively. An SRM power meter (Schoberer Rad Messtechniik, Germany) was used to measure pedaling speed and power, but power did not significantly differ according to pedal type. In order to maintain constant speed and power during pedaling, the training program I-Magic Trainers (Tacx, the Netherlands) and a metronome were used. Pictures of the three types of pedals are shown in (Figure 1). Flat pedals were manufactured "in-house" (Lee et al., 2014). For the clip pedals, the toe clips were acquired from Shimano (DuraAce Pedals PD-7400 with toe clips, Shimano Inc., Japan) and attached to the front of the flat pedals. For the cleat pedals, cleats were obtained from Shimano (SH-XC30, Shimano Inc., Japan), and a fixation device was added to the upper cover of the flat pedals to enable attachment of the cleats. All the pedals were weighted before the experiment to confirm that the weights were identical. For all the pedal types, the footwear used consisted of Shimano cleats with the cleats removed from the bottom.

Figure 1. Pedal type (left top: flat, right top: clip, and bottom: cleat)

3. Experiment procedure

Prior to the experiment, the participants underwent sufficient stretching and warm-up. Next, 6 reflective markers were affixed to the right lower limb based on the plug-in set. The ASIS marker was affixed to the anterior superior iliac spine; the greater trochanter marker, to the

great trochanter of the femur; the knee marker, to the lateral epicondyle of the knee; and the ankle marker, to the lateral malleolus. The heel and toe markers were affixed so as to be parallel to the ground. EMG measurements were taken from the vastus lateralis (VL), biceps femoris (BF), gastrocnemius medial (GM), and tibialis anterior (TA) muscles of the right leg. As joint lengths and ratios differed for all the subjects, the saddle height was adjusted according to Holmes' 25° knee angle method in order to construct identical pedaling conditions for all the subjects (Holmes et al., 1994). This means that the saddle height is adjusted so that the knee joint viewed from the sagittal plane has a medial angle of 155° (i.e., identical to Holmes' 25° knee angle) when the pedal is located at the BDC. Each subject maintained pedaling at a constant speed (60 RPM) for 3 minutes, with the saddle height set as described earlier, the same anteroposterior position of the seat, and the same load. The experiment was performed twice for each type of pedals. In between experiments, the subjects rested for 15 minutes, which was sufficient time to allow the elevated heart rate after the experiment to return to its resting rate prior to the experiment (Seo et al., 2012). In order to account for muscle fatigue, each pedal type was tested on a different day for 3 days.

4. Data analysis

All the data obtained during the 3-minute pedaling periods were stripped of the first and last 30 seconds, and the mean values from the remaining 2 minutes of steady pedaling were used in the analysis. In order to eliminate noise, 3-D movement data (sampling frequency: 120 Hz) were passed through a second-order zerolag Butterworth filter with a cutoff frequency of 6 Hz. The EMG data (sampling frequency, 1,200 Hz) were passed through a fourth-order zerolag Butterworth filter by using a 15- to 500-Hz bandpass, full wave rectification was implemented, and then smoothing was performed by using the mean value at 40 ms (Albertus-kajee et al., 2010). In order to analyze each pedaling phase, the EMG data were divided into 4 phases (phase 1: 330~30°, phase 2: 30~150°, phase 3: 150~210°, and phase 4: 210~330°) and compared (Dorel et al., 2010, Bae et al., 2014; Figure 2). MATLAB R2013a (Mathworks Inc., USA) was used for all data analysis.

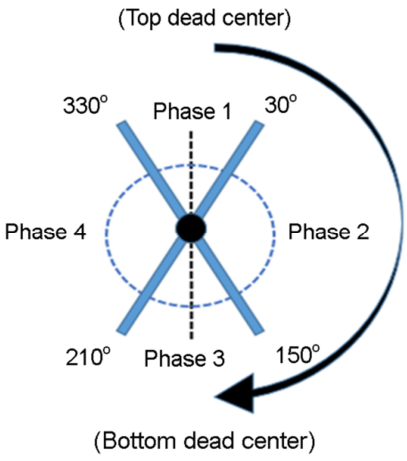

Figure 2. Definition of the pedaling phase

1) Kinematic analysis

During pedaling, the maximal flexion and extension angles of the knee and their timing, the maximal dorsiflexion and plantarflexion angles of the ankle and their timing, and the range of motion (ROM) were obtained. All the joint angles were considered in the sagittal plane. The position of the pedal was identified by defining the position with the highest point of the pedal arm around the crankset as 0° (top dead center [TDC]) and the lowest angle as 180° (BDC). The angle of the pedal arm at maximum extension (or plantarflexion) of the joint was defined as the maximum extension (or plantarflexion) timing, and the angle of the pedal arm at maximum flexion (or dorsiflexion) of the joint was defined as the maximum flexion (or dorsiflexion) timing. The ROM was defined as the difference between the angle of maximal flexion and the angle of maximum extension. The definitions of joint angles used in this study are presented in (Figure 3).

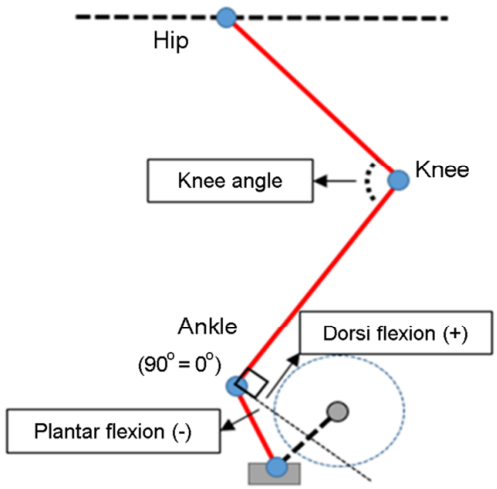

Figure 3. Definition of the joint angle

2) Muscle activity analysis

Muscle activities were performed on 4 muscles (VL, TA, BF, and GM) of the right leg that were activated during pedaling. From the measured EMG data, we calculated the following variables: the peak, at which muscle activity was highest, and the peak timing, which shows the time at which the highest value was obtained relative to the crankset. In addition, integrated EMG (iEMG) was calculated for each phase as the sum of muscle activity.

5. Statistical processing

In order to identify a significant difference according to pedal type, repeated-measures analysis of variance (ANOVA) was performed by using IBM SPSS v21 (IBM, USA). Post hoc comparisons were made by

using Bonferroni's multiple comparison method. The significant level was set as $\alpha = 0.05$.

RESULTS

1. Kinematic results

The kinematic results for different pedal types are shown in (Table 1). The maximum flexion and extension angles of the knee joint for flat pedals were 4.71° and 7.94° larger than those for clip pedals, and 3.10° and 8.05° larger than those for cleat pedals. The maximum dorsiflexion angle of the ankle was 8.00° larger than that for clip pedals and 6.73° larger than that for cleat pedals. The maximum plantarflexion angle of the ankle was largest for the clip pedals, at 4.46° larger than that for the flat pedals and 2.22° larger than that for the cleat pedals. The knee ROM for the flat pedals was 3.54° and 4.95° larger than those for the cleat and clip pedals, respectively, and the ankle ROM was also larger for the flat pedals by 3.54° and 4.49°, respectively.

Table 1. Kinematic results according to pedal type (*, #: significant difference, mean ± SD; $p < .05$: Bonferroni, ns = not significant (Unit: degrees)

Joint		Knee					Ankle				
Pedal type		Flexion max	Flexion timing	Extension maximum	Extension timing	ROM	Dorsi flexion maximum	Dorsi timing	Plantar flexion maximum	Plantar timing	ROM
Flat	mean	76.33*	18.36*	148.45*,#	195.67	72.12*,#	-0.78*	318.78	23.38	173.67*	24.16
	SD	4.23	2.50	6.36	1.66	4.66	4.73	12.66	5.25	10.55	4.60
Clip	mean	71.62*	17.89	140.51*	196.11	68.89*	7.22*	321.11	27.84	153.89	20.62
	SD	4.08	1.62	4.73	1.62	4.56	5.54	14.33	4.32	29.75	3.99
Cleat	mean	73.23	16.67*	140.40#	196.67	67.17#	5.95	317.33	25.62	147.00*	19.67
	SD	2.93	3.46	3.10	2.40	4.08	7.17	15.63	7.38	22.92	5.06
p-value		**0.01***	**0.03***	**0.00*** **0.00#**	ns	**0.01*** **0.00#**	**0.00***	ns	ns	**0.04***	ns

Table 2. iEMG results by phase (*: significant difference, mean ± SD; $p < .05$: Bonferroni; ns = not significant (Unit: mV)

Muscle	Pedal type	Phase 1	Phase 2	Phase 3	Phase 4	Total phase
VL	Flat	**0.80 ± 0.32***	1.65 ± 0.56	0.17 ± 0.06	0.38 ± 0.12	3.00 ± 0.91
	Clip	0.57 ± 0.07	1.59 ± 0.28	0.23 ± 0.07	0.46 ± 0.16	2.85 ± 0.25
	Cleat	**0.65 ± 0.26***	1.72 ± 0.62	0.19 ± 0.08	0.41 ± 0.11	2.97 ± 0.97
	p-value	**0.03***	ns	ns	ns	ns
TA	Flat	0.71 ± 0.52	0.73 ± 0.61	0.28 ± 0.22	0.92 ± 0.54	2.64 ± 1.81
	Clip	0.48 ± 0.23	0.50 ± 0.14	0.23 ± 0.08	0.69 ± 0.24	1.91 ± 0.51
	Cleat	0.49 ± 0.30	0.48 ± 0.19	0.20 ± 0.07	0.63 ± 0.25	1.80 ± 0.70
	p-value	ns	ns	ns	ns	ns
BF	Flat	0.21 ± 0.06	0.66 ± 0.22	0.50 ± 0.21	0.51 ± 0.16	1.88 ± 0.52
	Clip	0.25 ± 0.07	0.71 ± 0.17	0.40 ± 0.11	0.52 ± 0.14	1.89 ± 0.45
	Cleat	0.21 ± 0.06	0.71 ± 0.27	0.48 ± 0.21	0.60 ± 0.31	2.00 ± 0.65
	p-value	ns	ns	ns	ns	ns
GM	Flat	0.21 ± 0.08	0.96 ± 0.28	0.55 ± 0.22	0.54 ± 0.14	2.27 ± 0.63
	Clip	0.24 ± 0.08	1.04 ± 0.30	0.59 ± 0.19	0.61 ± 0.18	2.48 ± 0.57
	Cleat	0.19 ± 0.06	0.81 ± 0.18	0.50 ± 0.14	0.56 ± 0.21	2.06 ± 0.41
	p-value	ns	ns	ns	ns	ns

Note: VL: Vastus lateralis, TA: Tibialis anterior, BF: Biceps femoris, GM: Gastrocnemius medial

Table 3. Peak and peak timing according crank angle EMG (mean ± SD, $p < .05$: Bonferroni; ns = not significant (Unit: peak = mV, peak timing = crank angle)

Pedal type	VL		TA		BF		GM	
	Peak	Peak timing	Peak	Peak timing	Peak	Peak timing	Peak	Peak timing
Flat	0.02 ± 0.01	53.78 ± 26.15	0.02 ± 0.01	308.00 ± 77.44	0.01 ± 0.00	152.67 ± 45.03	0.01 ± 0.00	140.44 ± 9.37
Clip	0.02 ± 0.00	72.11 ± 15.58	0.01 ± 0.00	308.67 ± 68.13	0.01 ± 0.00	135.89 ± 19.27	0.02 ± 0.01	137.78 ± 19.60
Cleat	0.02 ± 0.01	66.33 ± 19.99	0.01 ± 0.01	329.56 ± 13.32	0.01 ± 0.01	146.56 ± 38.15	0.01 ± 0.00	139.99 ± 27.26
p-value	ns	ns	ns	ns	ns	ns	ns	ns

At the knee joint, maximum extension angle, maximum flexion angle, maximum flexion timing, and ROM all showed significant differences for flat pedals, with only maximum extension timing failing to show a significant difference. The maximum flexion angle showed a significant difference between the flat and clip pedals, the maximum flexion timing showed a significant difference between the flat and cleat pedals, and the maximum extension angle and ROM showed a significant difference for the flat pedals with both the cleat and clip pedals.

At the ankle joint, only the maximum dorsiflexion angle and maximum plantarflexion timing showed significant differences. The maximum dorsiflexion angle showed a significant difference between the flat and clip pedals, while the maximum plantarflexion timing showed a significant difference between the flat and clip pedals.

2. Muscle activity results

The results for muscle activity according to pedal type are presented in (Tables 2 and 3). Neither the peak activation nor peak activation timing for the four muscles VL, TA, BF, and GM showed any significant differences according to pedal type. When the iEMG was compared according to pedaling phase, only the VL muscle in phase 1 showed a significant difference between the flat and cleat pedals, at 0.80 ± 0.32 mV and 0.65 ± 0.26 mV, respectively. No other significant differences were found according to pedal type under any other conditions.

DISCUSSION

This study confirmed joint kinematics and muscle activity characteristics in novice cyclists when pedaling using flat, clip, and cleat pedals. For all the subjects, the pedaling speed was controlled to be as close to 60 RPM as possible. The saddle height was determined by using the knee angle method in order to minimize differences in the subjects' physical characteristics such as body segment length. For the knee angle method, the subject adopts the pedaling position on a fixed cycle and the saddle height is positioned so that the knee angle is 25° (or 155° by the definition in this study) when the pedal is at its lowest point relative to the crankset. This is known to be the saddle height that allows optimal pedaling according to many previous studies (Tamborindeguy & Bini, 2011). The reason for using this method was to minimize the differences in pedaling conditions, which allows a more accurate comparison of kinematics and muscle activity characteristics according to pedal type.

The kinematic results in this study showed that the differences in the knee joint variables were greater than those in the ankle joint variables. This result differs from our expectation that the pedal type would have a greater effect on the ankle joint owing to its proximity. The reason for this is thought to be that novices show less freedom in movement of the ankle joint than elite athletes, in spite of differences in pedal type (Chapman et al., 2007).

Differences at the ankle joint led to differences in knee movement. The maximum flexion angle of the knee joint showed a difference between the flat and clip pedals, which resulted from the difference in maximum dorsiflexion as the pedal passes the TDC, where the knee flexion is at its greatest. In other words, when dorsiflexion occurs at the ankle, the flexion angle at the knee becomes smaller. Meanwhile, the maximum extension angle at the knee joint showed a difference for flat pedals relative to clip and cleat pedals. The maximum knee extension is achieved before the pedal passes the BDC, and the differences in maximum extension angle also cause differences in knee ROM. Knee joint ROM was larger for the flat pedals than for the clip and cleat pedals, whereas the clip and cleat pedals showed similar knee ROM. At the ankle joint, although maximum plantarflexion angle did not show a significant difference, maximum plantarflexion timing was approximately 20° later for the flat pedals than for the other two pedal types. This indicates that the subjects completed the push-down strategy between the TDC and BDC and switched to dorsiflexion more rapidly with the clip and cleat pedals. This is because unlike flat pedals, the clip and cleat pedals allow the rider to exert force during the recovery phase. In addition, the positive values for maximum dorsiflexion angle indicate that dorsiflexion of the ankle did not occur for the clip and cleat pedals. This can be explained by the iEMG measurements in the pedaling phase, in which the flat pedals showed higher mean activity of the TA muscle, which is responsible for dorsiflexion, in phases 3 and 4. Novices are less familiar with the application of a pulling force to the pedals than elite cyclists (Chapman et al., 2007). Moreover, because they are usually more familiar with the use of flat pedals, so even when they are using pedals that allow a pulling force, such as clip or cleat pedals, novices continue to pedal with a pushing force alone. This can be explained by the fact that different pedal types showed no difference in the muscle activities of the BF and GM, which are mostly used in phases 2 and 3 when the pushing force is applied. In a previous study that compared muscle activation between different pedal types in elite

cyclists, muscle activation was reported to decrease with cleat pedals relative to clip pedals (Cruz & Bankoff, 2001). However, the results of this study showed no difference in muscle activation between the clip and cleat pedals. Therefore, differences in pedaling characteristics between elite athletes and novices can be expected. No significant differences were found in peak muscle activation or peak muscle activation timing. This means that the use of a particular muscle did not increase or decrease according to pedal type.

Integrating the kinematic and muscle activation results, we found that movements of the knee and ankle joints were larger with the flat pedals and that movement of the ankle joint was restricted with the clip and cleat pedals. Lower muscle activation when maintaining the same pedaling speed and power indicates that less force and energy are being used to travel the same distance. Hence, the fact that the VL activity was higher in phase 1 with the flat pedals can be interpreted to mean that the clip and cleat pedals are more efficient in the conversion of pulling force to pushing force. In terms of improving pedaling performance, for novices to use clip and cleat pedals more efficiently, they would need to follow a strategy of pulling the pedals, as used by elite cyclists. In future studies, we aim to examine the effects of pedal type on forces and to verify the differences between elite cyclists and novices in their abilities to use the pulling strategy that is characteristic of clip and cleat pedals.

CONCLUSION

This study examined the effects of pedal type on joint kinematics and muscle activation in novice. The results showed greater movement of the joints when using flat pedals, and ankle dorsiflexion in particular did not occur with the use if clip and cleat pedals. Nevertheless, no difference was observed in the amount of muscle activation. This indicates that the subjects did not take advantage of the strength of the clip and cleat pedals, which reflects the ability to utilize a strategy of pulling the pedals. The reason is thought to be that novice are not familiar with the use of force to pull the pedals. Therefore, effective use of clip and cleat pedals requires adaptation and effort to use a pulling strategy for pedaling.

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