KJSB

Korean Journal of Sport Biomechanics 2017; 27(1): 75-81
http://dx.doi.org/10.5103/KJSB.2017.27.1.75
http://e-kjsb.org eISSN 2093-9752

ORIGINAL

Analysis of Changes in Stride Length, Time, and Electromyography Finding Depending on Athletic Crouch Start Method

Kyungill Lee[1], Wanki Hong[1], Eung Gyu Kim[2]

[1]Department of Physical Education, Chosun University, Gwangju, South Korea
[2]Department of Physical Education, Graduate School of Chosun University, Gwangju, South Korea

Received : 15 February 2017
Revised : 28 March 2017
Accepted : 28 March 2017

Corresponding Author
Wanki Hong
Department of Physical Education, University of Chosun Pilmun-daero, Dong-gu, Gwangju, 61452, South Korea
Tel : +82-10-3794-2075
Fax : +82-62-232-8834
Email : bmw2053@naver.com

Objective: The purpose of this study was to compare and analyze the kinematic variables and electromyography (EMG) findings that change with varying characteristics of crouch start and feedback provision, and to provide the fundamental data for record improvement in 400 mH.

Method: Four short-distance runners participated in the experiment. The analyzed variables were elapsed time per interval, stride length, and muscle activities in three lower limb muscles. These variables were analyzed by using Kwon3d XP and Noraxon Myoresearch. The participants were subjected to three conditions, including two conditions that relate to the thrusting foot on the rear block and another condition pertinent to feedback provision.

Results: In terms of a one-step interval, the elapsed time in condition A was longer than that in condition B, and the one after the feedback was the longest. The stride length of a one-step interval was the longest in condition A. The stride length of a two-step interval was the shortest in condition A. The muscle activity during a one-step interval showed differences in vastus medialis and medial gastrocnemius, with condition A being the highest.

Conclusion: When the non-dominant left foot was located at the back, negative results were observed in terms of elapsed time and stride length. Moreover, an imbalance in muscle activity was observed between the left and right feet when the left foot was placed at the back. As a result, significant differences in elapsed time, stride length, and muscle activity were observed depending on the foot placed on the rear block. In conclusion, we identified the characteristics of crouch start in 400 mH, and a specialized program must be suggested.

Keywords: 400 mH, Feedback, Muscle activity, Crouch start

INTRODUCTION

In the past, Asian sprinters accepted their physical inferiority to world-class sprinters as an insurmountable condition. However, China's sprint superstar Liu Xiang, also known as the "Yellow Bullet", proved that Asian athletes are not outcasts in sprint running by grabbing the gold medal in 110-m hurdles at the Athens 2004 Olympics. Furthermore, Japan astonished the world at the 2016 Summer Olympics in Rio de Janeiro when they won the silver medal at the men's 400-m relay, only to be outsped by Jamaica, a sprinting superpower. Japan and China, whose athletes have similar physical conditions as Korean athletes, are certainly narrowing their gap in track-and-field records with the world records—and not by accident. Japan made profound investments in sports science since 1990 to utilize advanced technologies to improve their track-and-field performance. China also engaged in a long-term systematic preparation by appointing coaches, endeavoring to discover promising young athletes, and implementing scientific training methods (Lee, 2009). On the other hand, Korea has been demonstrating uncompetitive performance in sprint running in international competitions for several years and is merely watching China 'sand Japan's performance in envious awe. Things are not much different for 400-m hurdles, the topic of this study. Since Hong-Chul Hwang set the Korean record of 49.80 s, breaking the 50-s barrier in 1990, a record markedly short of the world record of 46.78 s, the record has not been broken.

Four hundred-meter hurdles fall under sprint events along with 100-, 200-, and 400-m sprint running. Sprints are broken down to start, start dash, transition, maximizing speed, and finish. For 100-m sprints, the start accounts for 10~15% of the entire race (Back, Kwon, & Sung, 2002). Hence, mastering the starting techniques has been consistently emphasized in sprint running (Harland, 1997).

One of the typical features of 400-m hurdles in Korea is that the 400-m sprinter also competes in the 400-m hurdle. In fact, nine out of 11 male high-school 400-m hurdlers at the 45th National Track Championships in 2016 also competed in the 400-m sprint (http://www.-

kaaf.or.kr). One common feature between the two events is the crouching start, but other factors must be considered. Interviews with Korean track coaches and athletes revealed that most athletes with right-leg dominance place their right foot on the back block for 400-m sprints but place their left foot on the back block for 400-m hurdles to hurdle with their dominant leg because the number of strides to the first hurdle is usually an odd number (23 strides in general). In other words, athletes switch their legs for the crouching start for hurdling. This causes a sense of discrepancy, and such difference in the starting position would have different consequences.

Most studies on the crouching start have only examined 100-, 110-, or 200-m sprints or hurdles. With the exception of a study that investigated the physical functions of athletes (Hwang, 2001), no study has been conducted on 400-m hurdles in Korea. Furthermore, studies abroad have generally performed a kinematic analysis, such as examining hurdling rhythms (Zhongyuan, 2003) and hurdling speeds in the maximum speed phase (Xudong, 2007). Starts in 400-m hurdles have not been investigated despite its importance. Therefore, this study was aimed at examining the differences caused by the position of the dominant leg and changes in the athletes after providing immediate feedback based on the results. Feedback, an important variable of motor learning, refers to the information provided to the learner about the motion itself or the results and assessments of the motion (Schmidt, 1991). Based on Shapiro's (1977) argument that immediate feedback to the participants after performance is the most effective in promoting motor learning, the present study seeks to examine the differences after providing immediate feedback.

Previous studies have stressed the importance of technical improvement in the early start phase through additional training because the start phase is a critical component of short-distance running such as 100- and 200-m sprint running (Lee, 2014). The starting phase comprises the thrust off the block, length of the first stride, trunk angle, and relevant muscle activity (Shin & Park, 2003; Choi & Oh, 2015). The force that pushes off the block—the thrust—determines early acceleration, and a long first stride is made based on this thrust. Placing the dominant leg on the back block would lead to longer stride and higher muscle activity than when the non-dominant leg is placed on the back block. Providing feedback to the athletes regarding the differences caused by placing the non-dominant leg on the back block and observing their changes would generate important basic data for the additional training emphasized by Lee (2014). Thus, this study analyzed the starting motions of 400-m hurdles under two conditions, which are placing the dominant or non-dominant leg on the back block. After analyzing the problems of 400-m hurdle starts with electromyography (EMG) based on the early starting motions for 400-m sprint running, feedbacks were given to the athletes to examine the changes brought upon by immediate learning effects.

METHODS

1. Subject

Four athletes—two 400-m runners registered at the Korea Association of Athletic Federations (KAAF) and two male high-school athletes who had competed at the National Championships—were enrolled in this study. All four athletes have competed in both 400- and 400-m hurdles in the past. None of the subjects had a medical illness, and they were enrolled in this study after providing informed consents. Their general characteristics are delineated in Table 1.

Table 1. The general characteristics of the research subjects

Player	Age	Height (cm)	Weight (kg)	Career (year)	400-m Record (s)
A	22	174.0	68.3	7	49.5
B	21	175.7	71.1	8	48.9
C	19	174.2	69.8	7	48.6
D	18	176.3	67.9	6	49.1

2. Data processing

This study measured elapsed time, stride length, and muscle activity. Based on previous studies that emphasized the importance of the first step off the starting block, which is the initial explosive acceleration from a crouching start position (Choi & Oh, 2007; Sin & Oh, 2002; Mero & Komi, 1990; Bunn, 1972), the elapsed time, stride length, and muscle activities from the starting position to the second step were analyzed via the methods explained as follows:

1) Elapsed time and stride length

A square calibration frame (1 × 3 × 1 m) with calibration points on the urethane track was installed to include the entire starting phase. Four high-speed cameras (EX-F1, Japan) were used to analyze elapsed time and stride length at an exposure time of 1/320 s and a shutter speed of 300 frame/s. Markers were attached at the great toe for coordinate digitizing. Three-dimensional coordinates were calculated via the direct linear transformation (DLT) method suggested by Abdel-Aziz Karara (1971) after syncing with the calibration points and coordinate markers. Data were analyzed by using the Kwon3D XP software (Visol, Korea).

2) Electromyography

To collect EMG data, six wireless surface electrodes were attached to the vastus medialis (VM) located on the surface in both quadriceps, medial gastrocnemius (MG), and biceps femoris (BF)—the agonist muscles of the crouching start—based on the literature (Shin & Park, 2003; Back, Kwon, & Sung, 2002) (Figure 1).

EMG data were low-pass filtered by using a 10-Hz high-pass filter and 250-Hz low-pass filter. To standardize the EMG data for each pa-r ticipant, the maximum voluntary isometric contraction (MVIC) by muscle was measured and standardized by using the following equation:

$$nEMG = \frac{EMGraw}{EMGmax}$$

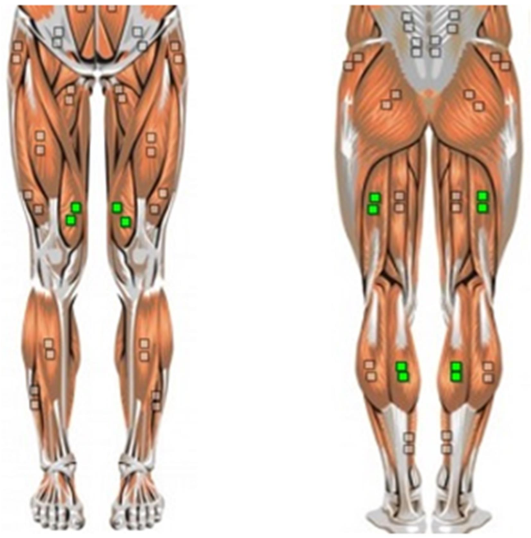


Figure 1. The placement of surface EMG electrodes and muscle measurements

Here, nEMG refers to the standardized integral EMG value, EMGraw refers to the actual EMG value, and EMGmax refers to the baseline maximal static contraction value. The baseline maximal static contraction was measured by using the methods shown in Table 2.

Table 2. Measurement method of maximum static contraction EMG

Corresponding muscles	Methods
(VM)	It is measured when the subject is sitting on a table with his feet off the ground, bending his legs at 90° and stretching them right away while the experimenter gives the subject resistance.
(MG)	It is measured when the subject lifts his heel, with the experimenter standing up behind the subject and pushing down the subject's shoulders.
(BF)	It is measured when the subject is lying down on the stomach with his knee bended 90°, exerting strength against the experimenter, who holds the subject's ankle and exerts an opposite force.

3. Experimental procedure

Prior to the experiment, the participants warmed up and practiced the two different types of starts for at least three times each. The participants' MVIC was measured first, and the experiments were all conducted on the same day to ensure reliability of the EMG electrode attachment sites. The participants had a 20-min break after performing one condition to inhibit any residual effects of the previous experiment as much as possible. Considering that the 400-m hurdle event generally succeeds the 400-m sprint event in competitions, the participants performed the crouching start with the right foot on the back block first, followed by the crouching start with the left foot on the back block. The third experiment was the same as the second experiment but was performed after receiving a 3-min feedback. A college track coach and the investigator gave the athletes feedback on the differences between 400 m and 400 mH based on the EMG data. The details of the feedback are shown in Table 3. Based on previous reports that feedbacks stimulate learners to perform more effective functions during a course of motor learning by understanding errors in their movement and rectifying them (Thikey, Grealy, van Wijck, Barber, & Rowe, 2012) and that elite athletes have higher muscle activity in the dominant leg (Shin & Park, 2003), the investigator interpreted muscle activity in the lower limbs at starting, discussed the differences with the coach, and delivered the feedback to the athletes.

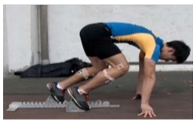
Table 3. Content of the feedback by each athlete

Subject	Feedback content
A	The muscle activity of the gastrocnemius is significantly low when the left leg is on the rear starting block than when the right leg is on the rear starting block. Push hard against the starting block by using the ankle.
B	Just like A, the muscle activities of the gastrocnemius and vastus medialis are low when the left leg is on the rear starting block. Make a start, unfolding one's knee strongly.
C	The muscle activity of the overall lower limb is low when the right leg is in front. Push hard against the block when the right leg is in front.
D	The muscle activity of the gastrocnemius varies in accordance with the change in the positions of the right and left legs. Push hard against the block when the right leg is in front.

The three conditions of the experiments were as follows: In condition A, the right foot—the dominant foot—was placed on the back block, which is the starting position for the 400-m sprint running. In condition B, the left foot was placed on the back block. In condition C, the participants performed the starting motion after receiving feedback based on the EMG differences in conditions A and B (Table 4).

To compensate for the small sample size, data were collected three times for each condition from each participant to use data from a total of 12 trials for analysis. The athletes were encouraged to demonstrate their best performance for the experiments. Block angles were set at 30° for the front block and 60° for the back block as suggested by Nathalie and Dauchateau (1992) and Back et al. (2002).

Table 4. Experimental condition

Condition	Methods
Condition a	 Right leg on the rear starting block
Condition b	 Left leg on the rear starting block
	After Feedback
Condition c	 Left leg on the rear starting block

4. Event

Two sections were set for analysis based on the starting blocks as shown in Figure 2.

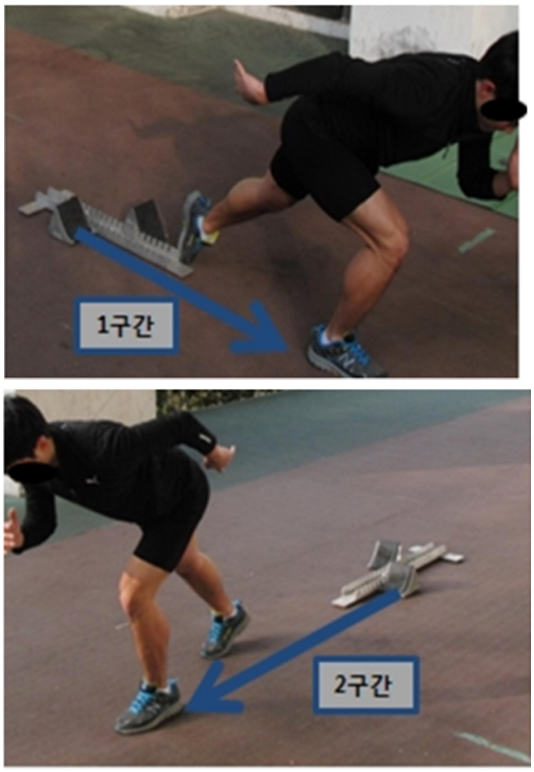


Figure 2. Interval setting. Step 1: Period from 0.1 s before the foot in the back block takes off to the time it first lands. Step 2: Period from 0.1 s before the foot in the front block takes off to the time it lands

5. Statistical analysis

The means and standard deviations were calculated by using the SPSS 21.0 software. Repeated one-way analysis of variance was used to examine the differences between the two conditions, and contrasts were used to investigate the differences for each condition. Statistical significance was set at 0.05.

RESULTS

1. Elapsed time and stride length

1) Elapsed time

Table 5 shows the features of the crouching start and changes in the durations of the two sections after feedback.

Table 5. The time required (unit: s)

Section	Condition a	Condition b	Condition c	F (p)
One-step Section	.298 ± .023	.311 ± .019*	.320 ± .011#	8.381 (.000)
Two-step Section	.353 ± .019	.352 ± .017	.342 ± .010	1.930 (.128)

*Significant difference between terms a and b
#Significant difference between terms b and c

As shown in Table 5, the duration of the step 1 section was longer when the non-dominant foot was placed on the back block than when the dominant foot was placed on the back block, and the athletes showed changes in the duration after receiving feedback (F = 8.381, p < .001). This suggests differences in the duration of the first step depending on the condition and that feedbacks induce change. On the other hand, no significant differences were found in the duration of step 2 in relation to different conditions (F = 1.930, p > .05).

2) Stride length

Table 6 shows the features of crouching start and changes in the stride length of the two sections after feedback.

As shown in Table 6, the length of the first stride was longer when the dominant foot was placed on the back block, and no significant changes were observed after feedbacks were given (F = 18.388, p < .001). On the other hand, the length of the second stride was longer when the non-dominant foot was on the back block (condition B), and the stride became longer after feedback was given (F = 13.584, p < .001).

Table 6. Step length (unit: m)

Section	Condition a	Condition b	Condition c	*F* (*p*)
One-step Section	1.28 ± .049	1.19 ± .035*	1.20 ± .032	18.388 (.000)
Two-step Section	2.20 ± .078	2.28 ± .081*	2.35 ± .080#	13.584 (.000)

*Significant difference between terms a and b
#Significant difference between terms b and c

2. Electromyography

Table 7 shows the features of crouching start and changes in the muscle activities (EMG) of the two sections after feedback.

As shown in Table 6, the VM showed high activity in step 1 when the dominant foot was placed at the back block, and feedbacks did not have any effect (F = 12.611, p < .001). The GM also showed high activity when the dominant foot was at the back block, and feedbacks did not induce any changes (F = 7.357, p < .01). By contrast, BF activity did not statistically vary in relation to the starting condition (F = 1.594, p > .05).

In step 2, the VM activity did not significantly vary according to the starting condition (F = 2.275, p > .05). The GM activity showed statistically significant differences in relation to the starting condition, but no significant differences in muscle activity were found between conditions A and B and between conditions B and C (F = 4.616, p < .05). The BF activity also did not statistically vary in relation to the starting condition (F = .700, p > .05), suggesting that muscle activity does not significantly differ in step 2.

DISCUSSION

The importance of starts in sprint running has been stressed in numerous studies. Although its contribution to the record is relatively small compared with that in 100- and 200-m sprints, starting techniques cannot be overlooked in 400-m hurdles as well because athletes must accelerate rapidly from the push-off from the starting blocks and reach the maximum velocity within the shortest amount of time (VanLngen Schenau et al., 1994).

In the crouching start for sprint running, steps 1 and 2—the phases in which the athlete initiates explosive movement—are important determinants of the record (Burn, 1972; Mero, 1988). However, as previously mentioned, switching the foot on the back block for 400-m hurdles also switches the feet for steps 1 and 2. For this reason, the present study investigated the differences between the two positions to provide feedbacks to the athletes based on EMG data and examined the changes in athletes. Owing to a lack of relevant literature, this study focuses the discussion on kinematic and EMG differences. The duration of step 1 varied considerably in relation to the starting condition and was the shortest in condition A, that is, when the dominant foot (right foot) was placed on the back block. This result can be explained in relation to stride length, the second kinematic variable. The stride length of step 1 was longer in condition A than in condition B. Long stride in a shorter period means that step 1 was completed rapidly. Lee and Shin (2016) reported that the duration of step 1 varied between the athletes of the national team and those who had competed in national competitions, where the former group had a shorter step 1. Choi and Oh (2015) reported that elite athletes with good records demonstrated longer first strides. Therefore, switching the foot during crouching start in 400-m hurdles would undermine the effectiveness of the start. One key aspect of the step 1 section is that its duration differs between conditions B and C. After receiving feedback, the duration increased while stride length remained unchanged. This finding shows that instead of improving performance in step 1, which was the end point of this study, feedback actually had an adverse effect on performance by increasing the duration of step 1. Although it is difficult to conclude, the inferior performance is speculated to be due to the difficulty of altering athletes' motor habits, which were familiarized through prolonged training, in a short period, necessitating prudent considerations in such approaches.

Stride length showed significant differences in step 2, where the stride was longer in condition B than in A, and in condition C than in B. That is, the right foot stride was longer when the right foot was placed on the front block, and the stride length increased after feedback. Furthermore, the duration of step 2 was the shortest in condition C, although not to a statistically significant extent. The difference shown in step 2 may be the result of the dominant (right) foot being placed at the front

Table 7. Maximum instantaneous activity (unit: MVIC%)

Section	Variable	Condition a	Condition b	Condition c	*F* (*p*)
One-step Section	VM	153.0 ± 29.94	139.5 ± 27.11*	140.5 ± 24.77	12.611 (.000)
	MG	227.5 ± 28.0	204.0 ± 24.5*	208.5 ± 28.7	7.357 (.007)
	BF	182.0 ± 24.5	185.2 ± 17.7	184.4 ± 22.1	1.594 (.208)
Two-step Section	VM	155.5 ± 25.5	168.0 ± 26.4	164.5 ± 22.3	2.275 (.129)
	MG	198.2 ± 30.0	210.9 ± 26.3	219.2 ± 24.2	5.506 (.032)
	BF	174.4 ± 26.3	178.6 ± 25.5	181.5 ± 22.5	.700 (.482)

*Significant difference between terms a and b and, as in step 1 of condition A, of the right foot having a stronger thrust force off the block. Steps 1 and 2 vary according to the position of the right foot. This seems to be due to the superior neuromuscular factors of the dominant foot, which is supported by Vuillermot, Pescatore, and Holper's (2009) finding that the neuromuscular performance of the non-dominant hand is inferior to that of the dominant hand. These findings will be useful in terms of providing the grounds for developing training methods.

Shin and Park (2003) mentioned that higher muscle activity of the right leg, which is placed at the back block during a crouching start, increases the leg's pushing force against the block, leading to a quicker start. The present study aimed to examine whether placing the non-dominant left foot on the back block produces the same results. First, VM and MG activities in step 1 varied according to the starting position, but no significant differences in muscle activity were found according to the starting position in step 2. The VM, the agonist muscle during a strong extension of the knee joint, is an important muscle to make a large extension during a crouching start. Lee and Choi (2010) stated that VM is important in step 1; in the present study, the VM activity differed by 139% in condition B (when the left foot was placed on the back block) and had lower intensity. The activity of the MG, a muscle that plays an important role when the ankle pushes off the block via plantar flexion, also differed in step 1 according to the starting condition, where its activity was the lowest in condition B. These two muscles contribute to a strong push off from the block for a strong and far landing forward. Back et al. (2002) reported that the activity of the two muscles at crouching start differed by more than 50% between non-athletes and athletes. As previously mentioned, this would result in a shorter duration and longer stride. After immediate feedback was provided based on the differences between conditions A and B, muscle activities did not significantly differ, presumably owing to the fact that the athletes' muscle mobilization has been optimized through training over a long period and that it is difficult to alter maximal muscle activities unless their muscle mobilization capacities are altered by offering strong stimuli on the muscles, such as special weight training (Wise, Gregory, & Proske, 1996).

Another notable aspect is the ratio of VM activity in steps 1 and 2. The body is unstable when starting off the starting block, so muscular interaction is important to eliminate the body's instability (Shin and Park, 2003). The ratios of steps 1 and 2 were similar in condition A at 153% and 155%, respectively, but were different in condition B at 139% and 168%, respectively, indicating an imbalance of the left and right muscle activity when the left foot was placed on the back block. These results suggest that a balanced mobilization of the lower limb muscles is important for an effective start in a 400-m hurdle. In conclusion, this study examined the differences according to the position of the dominant foot, which was the first hypothesis. However, the second hypothesis—whether athletes can overcome the differences after receiving feedback—was not verified. Future studies should examine whether more detailed feedbacks induce changes.

CONCLUSION

This study aimed at investigating the features of crouching starts in relation to the position of the foot and the differences in duration, stride length, and activity of the lower limb muscles after feedback. To this end, two 400-m runners of C University who were registered at the KAAF and two high-school male 400-m runners were evaluated to analyze the duration, stride length, and lower limb muscle activity in three conditions, with varying feet position and presence of feedback. The following conclusions were drawn based on the findings.

First, significant differences in duration and stride length of step 1 were found in relation to the condition of crouching start and feedback; the starting motion in condition B, when the left foot is placed on the back block, was not performed effectively. Second, a significant difference was found in stride length of step 2 in relation to the condition of crouching start and feedback; stride length differed according to the position of the right foot. Third, a significant difference was observed in muscle activity in step 1 in relation to the condition of crouching start and feedback; the muscle activity in step 1 was high when the dominant right foot was placed on the back block.

In conclusion, this study identified the features of crouching start in 400 mH and suggested the need of specialized programs. This study only analyzed steps 1 and 2 after starting in four athletes. In the future, a larger sample should be obtained to investigate the association between the start and the speed in the first 45-m section (distance from the block to the first hurdle) or the final record. Furthermore, as Cho and Kim (2000) argued that left arm movement at crouching start contributes to increasing acceleration, future studies should also analyze upper limb movement in addition to lower limb movement.

ACKNOWLEDGEMENTS

This study was supported by the 2014 Research Foundation of the University of Chosun.

REFERENCES

Abdel-Aziz, Y. L. & Karara, H. M. (1971). Direct Linear Transformation From Comparator Coordinates in Object-Space Coordinates in Close-Range Photogrammetry. Proceedings of the ASP Smpoium of Close-Range Photogrammetry. Urbana, IL.

Bunn, J. W. (1972). *Scientific Principle of Coach*. Englewood Cliff, Prentice-Hall Inc.

Choi, S. N. & Oh, J. H. (2015). Kinematical Comparative Analysis according to the Different Locations of Crouching Start Line and Starting Block. *Journal of Sport and Leisure Studies*, *30*, 699-711.

Harland, M. J. & Steele, J. R. (1997). Biomechanics of the sprint start. *Sports Medicine*, *23*(1), 11-20.

Hwang, S. H. (2009) Comparison between Hwang who still holds his record of 400 M hurdle at present, and Shon who represents Korea team. *Korean Society of Sports Biomechanics*, *11*(3), 77-99.

Hyung, H. B., Oh, S. K. & Bong, J. S. (2002). The comparative analysis of eletromyogram on athletes and non-athletes in crouching start movement. *Korean Journal of Physical Eduaction*, *41*(4), 581-589.

Kim, D. H. (2009). Suggestions to Revitalize the Competitiveness of Korean Sprint based on the Longitudinal Analysis. *Journal of Coaching Development*, *11*(4), 3-13.

Lee, J. H. & Shin, I. S. (2016) Kinematic Analysis for Crouching Start Movement of University Female Sprinters. *The Korean Society of Sports Science*, *25*(4), 1515-1527.

Lee, J. T. (2014). The Effect of 8 Weeks Athletics Class on Sprint Start Motion. *Korean Society of Sports Biomechanics*, *24*(3) 209-216.

Mero, A. & Komi, P. V. (1990). Reaction time and electromyographic activity during a sprint start. *European Journal of Applied Physiology and Occupational Physiology*, *61*(1), 73-80.

Mero, A. (1988). Force-time characteristics and running velocity of Male Sprinters during the Acceleration of Sprinting. *Research Quarterly for Exercise and Sport*, *59*, 94-98.

Nathalie, G. & Dauchateau, J. (1992). EMG and mechnical changes during sprint starts at different front block. *Medicine and Science in Sports and Exercise*, *24*(22), 1257-1263.

Schmidt, R. A. (1991). *Motor learning and performance: From principles to practice*. Human Kinetics, Champaign, IL.

Shapiro, D. C. (1977). Knowledge of results and motor learning in preschool children. *Research Quarterly*, *48*, 154-158.

Shin, S. H. & Park, K. J. (2003). Electromyography Analysis of Muscle Activities of Lower limb for Crouching Start Technique. *Korean Society of Sports Biomechanics*, *13*(2), 115-122.

Thikey, H., Grealy, M., van Wijck, F., Barber, M. & Rowe, P. (2012). Augmented visual feedback of movement performance to enhance walking recovery after stroke: study protocol for a pilot randomised controlled trial. *Trials*, *13*, 163.

van Lnden Schenau, G. L., Koning, J. J. & Groot, G. (1994). Optimisation of sprinting performance in running, cycling and speed skating. *Sports Medicine*, *17*(4), 259-275.

Vuillermot, S., Pescatore, A. & Holper, L. (2009). An extended drawing test for the assessment of arm and hand function with a performance invariant for healthy subjects. *Journal Neuroscience Methods*, *177*(2), 452-460.

Wise, A. K., Gregory, J. E. & Proske, U. (1996). The effects of muscle conditioning on movement detection thresholds at the human forearm. *Brain Research*, *135*(1), 125-130.

Xudong, X. I. (2007). A Study on the Speed Distribution of the Male's 400 m Hurdles Running Competition. *Journal of Sport Science and Technology*, *2*, 7.

Zhongyuan, T. (2012). A Research on the Contest Rhythm of World Man's 400m Hurdles. *Journal of Shenyang Institute of Physical Education*, *2*, 43.