THE FUNCTIONS OF THE LOWER EXTREMITY MUSCLES DURING THE DOUBLE-LEG PUSH-OFF

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Abstract:

The aim of the present study was to reveal the general (agonistic/antagonistic) functions of the lower extremity muscles during the double leg push off in a horizontal lying position. These muscles were vastus lateralis, vastus medialis (VAS), gluteus maximus (GLU), biceps femoris (BF), rectus femoris (RF), soleus (SOL) and gastrocnemius (GAS). One male athlete participated in the study. He performed 5 push-offs in 3 different starting positions. The kinematic trajectories were measured. The mathematical model of the human body was applied, the six muscular forces being the outer variables determining the action. The functions have been defined according to the partial derivative of the front surface force with respect to muscles' forces, that followed the Lagrange-Euler equations, describing the motion of the model. Comparing the values of how much muscles can affect movement, it is possible to set the criterion of motor control sensitivity, which defines the ultimate limit of a large range of starting positions, for which the general, close-to-optimal muscle coordination pattern enables performance with almost negligible reduction in the performance.

Key words: *muscle activation, coordination, agonist, push-off, motor control*

INTRODUCTION

The understanding of the mechanics of human movements is essential for the improvement of performance in many sports. Measurements concerning intermuscular coordination are therefore very important. Applying a mechanical model helps us to analyse and to better understand the dynamics of movement. The model may enable us to define exact muscular functions during a certain action. The model has to be sophisticated, yet simplified enough in order to provide accurate results. When applying the model, the initial presumptions and relevant parameters of the model are of great importance.

Several studies have been done concerning intermuscular coordination during explosive movements. There is always only one coordination pattern that results in optimal performance for simple, stereotyped actions. Confining to vertical jumps or actions like push-offs, the studies clearly show the proximal to distal activity succession of the lower extremity muscles (Bobbert and van Ingen Schennau, 1988). However, the starting positions are never the same. Small deviations in the initial position imply the motor control system is ultimately capable of generating the adequate muscle activation patterns. Sometimes it may lead to unsuccessful and less-controlled movement, which is less effective and consequently demands higher energy expenditure. However, there exists a certain muscle activation pattern that yields close to the optimal behaviour over a certain range of starting positions. That is how the nervous system reduces the complexity of the problem of generating the optimal coordination pattern (van Soest and van Ingen Schenau, 1998). It certain muscle functions deviate as much as the reduction then the performance is not acceptable.

The aim of the present study was to reveal the general (agonistic/antagonistic) functions of the leg muscles during the double leg push off in a horizontal lying position by applying a mathematical model of the human body. Comparing the values of how much muscles could affect the movement, it is possible to set the criterion for defining the ultimate limit of a wide range of starting positions, for which a general, close-to-optimal muscle coordination pattern exists.

METHODS

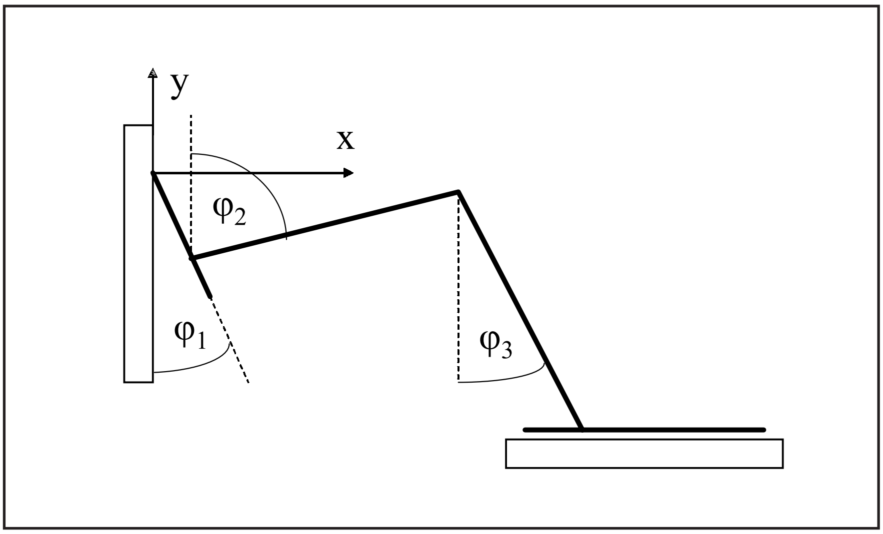
MEASUREMENT OF THE MOVEMENT

The push-offs were performed in a horizontal direction using a leg-press device (model M051, Technogym, Gambettola, Italy). The back support was lowered to the horizontal position so that the push-off in a lying position in a backward direction was possible (Figure 1). The force plate (model 9287, Kistler, Winterthur, Swiss) was attached to the front surface. One male (age 26 years, height 176 cm, mass 68 kg) participated in the study. He had given his consent prior to the experiment, since the study was conducted in accordance with the Helsinki-Tokyo declaration.

The athlete performed a push off with his legs with maximal power 5 times from 3 different starting positions. They were chosen in such a way that positions 1 and 2 were more ergonomic (usual) and position 3 was less ergonomic. The angular velocity of the knee joint extension was measured with a goniometer (Biometrics, Gwent, UK) fixed on the left knee joint. A potentiometer (custom made), connected to a cable that was fixed on to the left hip, was used to measure the distance between the hip and the fixed front surface. The horizontal hip velocity was obtained as a time derivative of hip coordinate in units of time. The kinematic trajectories of the body coordinates were calculated from the hip coordinate and knee angle in units of time. In order to prevent any possibleinjuries the actions were free only in the first 15 cm of push-offs.

The activations of 7 muscles were measured with an EMG telemetric device (Biotel 88, Glonner, Munich, Germany). The bipolar EMG electrodes (Hellige, Freiburg, Germany) were placed on the skin above the muscles of the left leg and the distance between the electrodes (from centre to centre) was 22 mm. The skin was prepared in order to reduce the interelectrode resistance under 5 k?. The electrodes were placed on the muscles *vastus lateralis* and *vastus medialis* (VAS), *gluteus maximus* (GLU), *biceps femoris* (BF), *rectus femoris* (RF), *soleus* (SOL) and *gastrocnemius* (GAS) in accordance with SENIAM recommendations (Hermens et al., 2000). The EMG and all the other signals were acquired at 1000 Hz. In order to quantify a muscle activation the raw EMG signal was rectified, averaged and smoothed with a low-pass filter. The time dependent EMG signal was transformed

Figure 1. *The body model. The body model is composed from four segments, the joints (ankle, knee, hip). The body position is exactly defined with angles* φ_1 *and* φ_2. *The left rectangular is a front surface of tension measuring device, the bottom one is support of the leg-press machine.*



proportionally to the relative muscle activation (Enoka, 1994), hereafter in the following text the relative muscle activations are denoted by a_i. The values of (dimensionless) a_i refer to the maximal activation of the i-th muscle, measured at maximal isometric contraction corresponding with $a_i = 1$. According to the muscle that acts with force within an interval (0, maximal muscle force), the respective a_i lies within the interval (0.1). The calculation of value a_{VAS} was based on the averages of the EMG signal values of the muscles *vastus lateralis* and *vastus medialis*.

The time dependent coordinates of the body joints and muscle activations a_i were calculated as an average of all the push-offs for each of the three starting positions.

DESCRIPTION OF THE MODEL

The 2D mathematical model of human body was applied, the six muscular forces being the outer variables determining the action. The model included 4 rigid, one-dimensional body segments (foot, shank, thigh and trunk) connected with muscles. The model could move only in the sagittal plane. The model of a single muscle was extremely simplified. It was described as a no mass bond, acting with force between two points of attachment to the bones. The muscle force-velocity and force-length dependences were neglected. The coordinates of the muscle attachments to the bones and other model parameters were determined according to Bobbert and Huijing (1990).

LAGRANGE-EULER EQUATIONS AND THE RELEVANT DERIVATIVES

In order to reveal the muscle functions during the push-off phase, the Lagrange-Euler equations describing the motion of the model were applied.

The body position was accurately determined with two angles φ_1 and φ_2. The first one is the angle between the vertical axis and the foot segment, whereas φ_2 is the angle between the vertical axis and the shank segment. The kinetics of the body was described with Lagrange-Euler equation with two angles $\varphi_a = \varphi_1, \varphi_2$ being the generalised coordinates:

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{\varphi}_a} - \frac{\partial L}{\partial \varphi_a} = \sum_j \vec{F}_j \cdot \frac{\partial \vec{r}_j}{\partial \varphi_a} \qquad (1)$$

The quality L denotes the difference between kinetic energy T and the potential energy V of the body, F_j forces of six muscles and r_j their respective coordinates of attachment. The equation (1) is followed by two coupled nonlinear second order differential equations

$$A_0 \ddot{\varphi}_1 + B_0 \ddot{\varphi}_2 + C_0 = G_0 \qquad (2)$$

$$D_0 \ddot{\varphi}_1 + E_0 \ddot{\varphi}_2 + F_0 = H_0 \qquad (3)$$

with coefficients $A_0, \ldots, H_0$ being very complex mathematical functions, derived from equation (1). The coefficients $A_0, \ldots, F_0$ were functions of two coordinates φ_1 and φ_2 and their time derivatives. The coefficients G_0 and H_0 were functions of muscle forces, consequently depending on a_i (because of the direct relation between muscle force and its relative activation a_i). The pushing force F (front surface force) could be expressed with angles φ_1 and φ_2 and their first and second-order time derivatives, and was therefore connected with muscle activations a_i (coeficients G_0 and H_0) according to equations (2) and (3). The angle between the vertical axis and the thigh segment, denoted by φ_3, was calculated from the values of the angles φ_1 and φ_2.

The relevant quality, that describes the global muscular functions, was said to be the partial derivative of front surface force F (perpendicular component) with respect to muscle activations a_i ($D_{F/a}$):

$$\frac{\partial F}{\partial a_i}$$

The derivative $D_{F/a}(t)$ depends on model parameters, time dependent generalised coordinates φ_1 and φ_2 and their time derivatives. With respect to the measured body kinetics, the derivative $D_{F/a}$ based on the Lagrange-Euler equation enabled us to determine the global muscle functions during the push off phase. It specified the sensitivity of the front surface force to muscle activations. The higher the derivate $D_{F/a}$ value, the bigger the change in force at the same activation change. Positive or negative derivative values signified a certain muscle as agonist or antagonist, respectively.

RESULTS

The starting and zhe final segment angles of the three different starting positions are presented in Table 1. The average times, front surface forces during push-off and average final velocities of the hips are presented in Table 2 for all the starting positions. It is evident that the average final velocities were almost the same at positions 1, 2 and 3, whereas there were only small differences

***Table 1**: The starting and final body segment angles.*

	position 1		position 2		position 3	
	start	*end*	*start*	*end*	*start*	*end*
foot	9.7^0	14.8^0	9.7^0	12.7^0	28.6^0	32.3^0
shank	83.8^0	93.9^0	65.5^0	74.3^0	61.3^0	71.6^0
thigh	48.5^0	60.7^0	55.9^0	65.3^0	61.9^0	71.6^0

The angles were measured between the vertical axis and a certain segment. The distances between the hips and front surface were constant for all the starting positions. The vertical distance between foot and frontal plane (the horizontal one) of the trunk segment were 37 cm, 20 cm and 12 cm for starting positions 1, 2 and 3, respectively. The foot segment was quite close to the front surface at starting positions 1 and 2 and far away for starting position 3.

between the times of push-offs and the average front surface forces. The measured EMG values during the push-off phase were transformed in order to get the relative muscle activations in units of time $a_i(t)$. The average values of $a_i(t)$ were calculated for all the starting positions regarding all the push-offs (Table 3). The average muscle activation of VAS, RF and GLU during push-off were more than two thirds of their absolute maximal values (corresponding with a_i=1). On average, the muscles VAS and RF were the most activated ones, whereas BF was the least activated one during the push-off phase. The overall average value of muscle activations was 0.57. The time dependent derivative $D_{F/a}(t)$ was calculated (Figures 2-7) for each muscle. During push-off, the values were negative only for the muscle BF (neglecting the values around 0 for GLU at starting position 2). The differences between the time dependent derivative $D_{F/a}$ for starting position 1 and 2 were quite small compared to starting position 3 for VAS, GLU, BF, RF (Figures 2-5),

***Table 2**: Times, forces and velocities of the body during the push-off.*

	time (s)	average force (N)	final velocity (m/s)
position 1	0.150	1078	1.22
position 2	0.132	1131	1.25
position 3	0.138	1100	1.25

The velocities were very similar regardless of the fact that the starting position was the least ergonomic. The longer time of the push-off phase is directly connected with a lower front surface force and vice versa.

***Table 3**: The average (dimensionless) muscle activations in all the push-offs and starting positions with their deviation values.*

muscle	average muscle activation a_i
VAS	0.685 ± 0.031
RF	0.685 ± 0.134
GAS	0.671 ± 0.024
GLU	0.604 ± 0.060
SOL	0.504 ± 0.019
BF	0.299 ± 0.115

The muscles VAS and RF were most activated during the push-off whereas the muscle BF was drastically the least activated one. The overall average of the average muscle activations was 0.57.

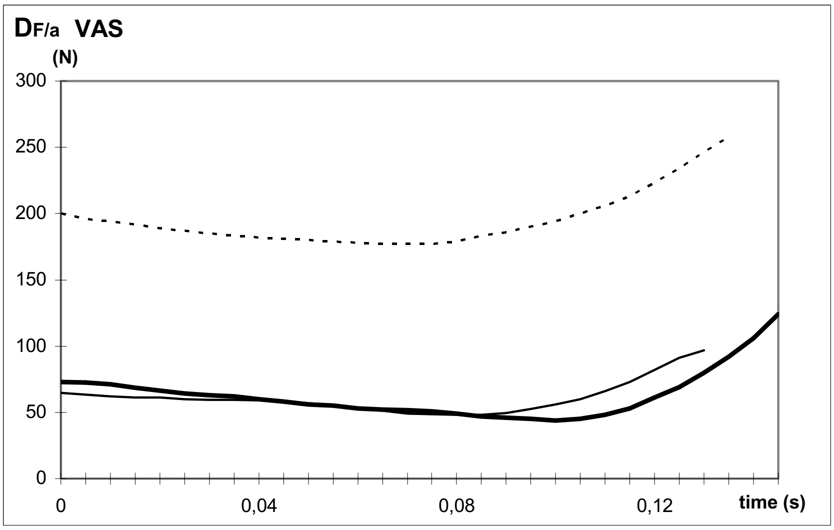


Figure 2. *Derivative of push-off force with respect to activation of m. vastus lateralis. Starting position 1 - fat line, starting position 2 - thin line, starting position 3 - dotted line. Lines' designations valid through figures 2 to 7.*

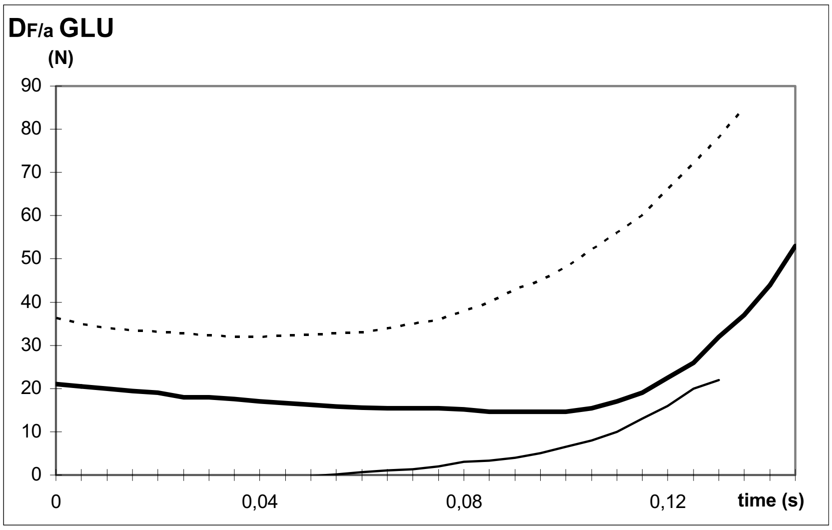


Figure 3. *Derivative of push-off force with respect to activation of m. gluteus*

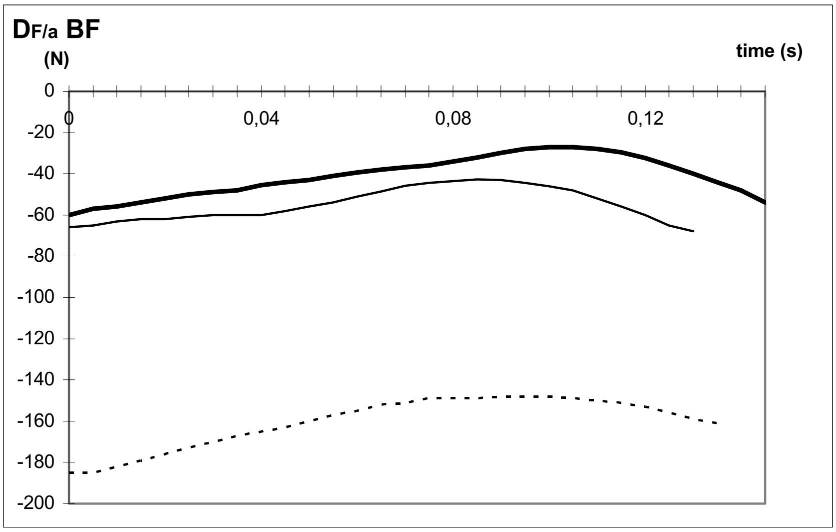


Figure 4. *Derivative of push-off force with respect to activation of m. biceps femoris*

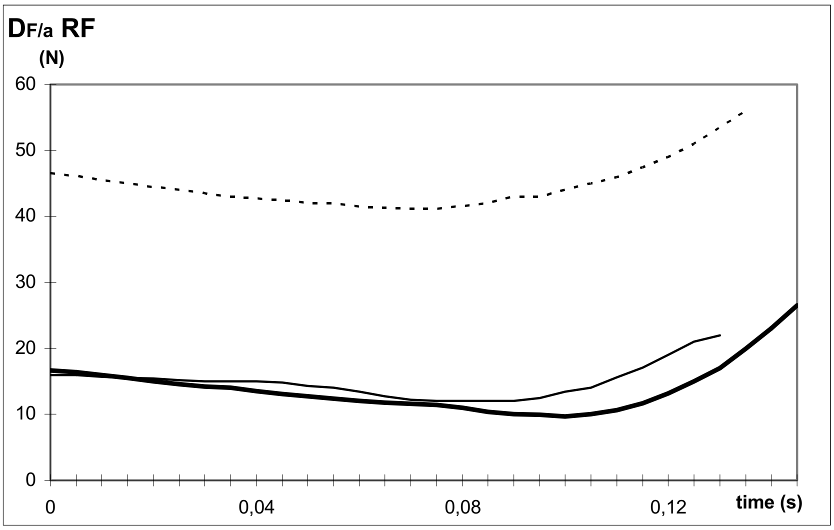


Figure 5. *Derivative of push-off force with respect to activation of m. rectus femoris*

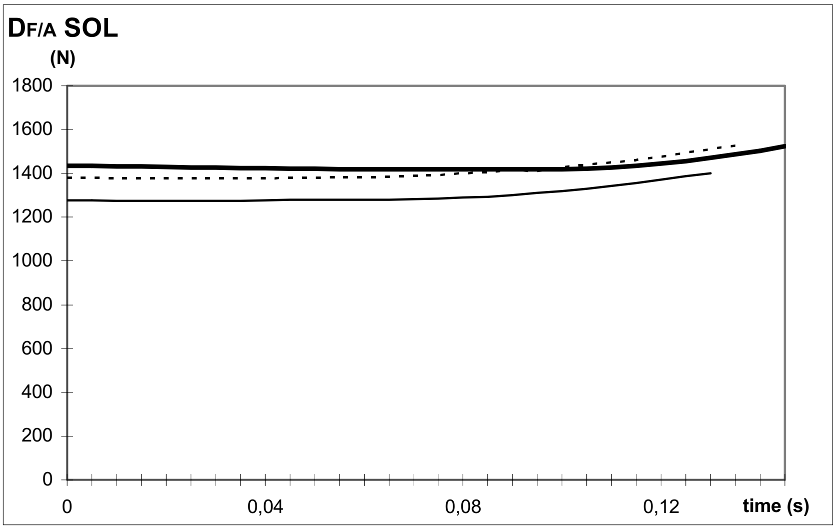


Figure 6. *Derivative of push-off force with respect to activation of m. soleus*

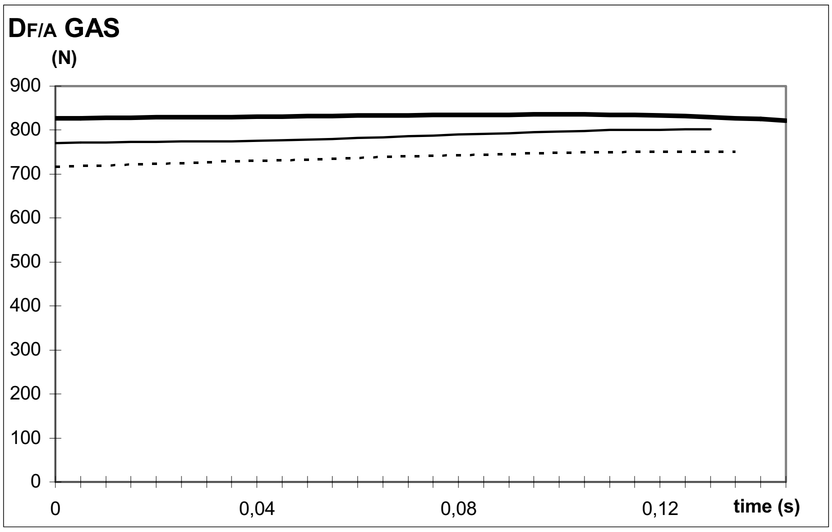


Figure 7. *Derivative of push-off force with respect to activation of m. gastrocnemius*

whereas there were practically no differences for SOL and GAS (Figures 6,7). The derivative tended to increase towards the final part of the push-off for the muscles VAS, GLU and RF, whereas it tended to decrease for the muscle BF. For example, a 1% higher activation of the muscle VAS caused a 2.0 N higher front surface force at the start of the push-off, whereas a 1% higher activation of the muscle BF decreased the front surface force at the start of the push-off for 1.8 N at the starting position 3.

DISCUSSION

The most important findings of this study were the differences in the sensitivity of the front surface force of the analysed muscles. The muscles GLU, VAS, RF, SOL and GAS proved to be agonists, while the BF role was antagonistic. Of the three different starting positions the more ergonomic ones (positions 1 and 2) showed a quite similar sensitivity of all the muscles. The muscles' functions at a less ergonomic starting position 3 where the heel was more distant from the front surface, was distinctive. Their sensitivity to activation was much greater than in the other two positions. Interestingly enough, no differences of the positions were found in SOL and GAS (Figures 6 and 7).

However, the above conclusions are to be discussed in more details. The push-off phase is a very complex motor action. The front surface force is not the only quality determining the efficacy of movement. Each muscle analysed has to be regarded as a flexor or extensor in every single joint as well. Another study has shown that every muscle is a two-fold extensor and a one-fold flexor or a two-fold flexor and a one-fold extensor, regarding the ankle, knee and hip joint (Hočevar, 1999). Therefore, the general role of a single muscle is only the sum of flexor/extensor functions in the joints. For example, the differences between the average activations of VAS and BF were more than two-fold (Table 3). That is because the muscles have different general functions. According to the derivative of force with respect to muscle activations $D_{F/a}$ that follows from equation (1), the general muscle functions could be determined for a single muscle. The calculations showed that a theoretical increase of all the muscle activations result in a bigger force on the front surface except for the muscle BF (Figures 2-7). The study showed that BF is an antagonist and that the other muscles (GLU, VAS, RF, SOL and GAS) are agonists during the push-off phase for all starting positions.

Because of the existence of a certain muscle activation pattern that yields close-to-optimal behaviour over a certain range of starting positions, small perturbations of the starting position imply very few deviations of performance. In such cases, a single general coordination pattern is sufficient in order to perform a wide range of positions almost without any reduction in performance. Counteracting so few perturbations and assuring the reduction in performance is as low as possible, is guaranteed by feedback mechanisms. The first order being the so-called preflexes, the viscoelastic muscle properties (muscle force-lenthg-velocity relation), that counteract the segments' position disturbances without any time delay (van Soest and van Ingen Schenau, 1998). If the perturbations of the starting positions increase significantly, the motor control is distributed. In Figures 2-7 the muscle influences can be compared for different starting positions, revealing their functions defined by the derivative of the front surface force with respect to the muscles' activation $D_{F/a}$. If the starting position 3 is compared to 1 and 2 for the muscles VAS, GLU, BF and RF, it is obvious that the values of derivative $D_{F/a}$ are three times higherer in starting position 3. It means that a small change in single muscle force at starting position 3 implies not only a much bigger front surface force, but also the changes in joint torques. The consecutive increase of the co-contraction in certain joints is followed by a lower degree of effectiveness and a higher degree of energy expenditure. If it is to be so, the small deviations of single muscle activation from the general coordination pattern at starting position 3 lead to bigger deviations in the trajectories of movement as well. The general coordination pattern could also be applied in the less ergonomic starting positions (like position 3), but higher peripheral feedback mechanisms have to be provided. The derivative $D_{F/a}$ could therefore be the measure of the range of the starting positions, where the general coordination pattern could be applied and where the motor control is still very high.

CONCLUSION

The present study revealed six functions of muscles during the push-off phase. The muscle BF proved to be an antagonist whereas the other muscles VAS, GLU, RF, SOL and GAS were agonists. According to motor control sensitivity two essential findings were realised. In the first place, sensitivity is greater in the final phase compared to the start of the push-off, and secondly, sensitivity is greater when the starting position is less ergonomic (i.e. unusual). From the last two findings we can draw the conclusion that motor action is more easily controlled at the start of the movement and within certain intervals of the starting positions (the so-called ergonomic starting positions) compared to the final phase of the push-off and to unergonomic positions. From a motor control point of view, this is a favourable situation since there is no need to have a larger number of motor programmes that are specialised for specific tasks and conditions.

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DINAMIKA AKTIVNOSTI // MEĐUMIŠIĆNA KOORDINACIJA NOŽNIH MIŠIĆA PRI SUNOŽNOM ODRIVU

SAŽETAK

UVOD

Matematički modeli mogu pripomoći boljem razumijevanju dinamike ljudskog kretanja. Usprkos pojednostavljivanju, model mora biti dovoljno kompleksan da bi dobiveni rezultati bili valjani i upotrebljivi u praksi. U dobroj izvedbi pojedinih gibanja jednostavnih, stereotipnih motoričkih aktivnosti (hodanje, trčanje, skokovi), u kojima sudjeluje veći broj mišićnih skupina, uvijek se pojavljuje jedan uzorak koordinacije mišićne aktivacije (motorički program). Dosadašnja istraživanja nedvojbeno potvrđuju proksimalno-distalni redoslijed aktivacije mišića donjih ekstremiteta pri sunožnom skoku u vis (Bobbert i Van Ingen Schennau, 1988). Početni položaji, međutim, nisu nikada potpuno jednaki. Svaka promjena početnog položaja uzrokuje malu promjenu aktivacije mišića. No ako su promjene početnog položaja prevelike, postojeći model aktivacije ne može više osiguravati optimalan mišićni učinak. Ipak, postoji, takozvani, 'optimalni' uzorak koordinacije aktivacije mišića koji omogućuje učinkovitost i pri određenom rasponu otklona od idealnih početnih položaja. Tako središnji živčani sustav racionalno pojednostavljuje kompleksnost optimalnoga koordinacijskog uzorka (Van Soest, Van Ingen Schennau, 1998). Drugo pitanje odnosi se na utvrđivanje graničnih vrijednosti unutar kojih je moguće koristiti isti kretni uzorak. Stoga je cilj ovog rada bio uz pomoć matematičkog modela ljudskoga tijela utvrditi globalne (agonist/antagonist) uloge pojedinih mišića pri sunožnom odrivu u ležećem položaju te opažati promjene u aktivaciji pojedinog mišića s obzirom na utjecaj različitih startnih pozicija.

METODE

Ispitanik (dobi od 26 godina, visine 176 cm, mase 68 kg) izvodio je vodoravne odrive na spravi 'nožna preša' (model M051, Technogym, Gambettola, Italija) u ležećem položaju (os trupa u smjeru odriva). Na odrivnu površinu bila je pričvršćena tenziometrijska ploča (model 9287, Kistler, Winterthur, Švicarska). Ispitanik je odriv izvodio iz tri različita položaja, definirana s obzirom na kut pod kojim je koljenski zglob bio pogrčen. U 1. početnom položaju koljena su inicijalno bila potpuno opružena, a u 3. maksimalno pogrčena. Iz svakoga je položaja ispitanik izvodio pet maksimalnih sunožnih odriva. U izvedbi odriva goniometrom se mjerila kutna brzina opružanja koljenskog zgloba te udaljenost zgloba kuka od odrivne površine, što je omogućilo da se, na temelju poznavanja dužina pojedinih segmenata donjih ekstremiteta, izračunaju sve koordinate tijela u vremenu. Kako bi se uklonio rizik od ozljede, odriv je bio slobodan samo u prvih 15 cm pokreta. Telemetrijskim EMG uređajem (Biotel 88, Glonner, Munchen, Njemačka) mjerene su aktivacije 6 mišića: m. vastus lateralis i m. vastus medialis (VAS), m. gluteus maximus (GLU), m. biceps femoris (BF), m. rectus femoris (RF), m. soleus (SOL) i m. gastrocnemius (GAS). Po dvije bipolarne elektrode bile su postavljene na kožu iznad pojedinih mišića lijeve noge na razmaku od 22 mm (otpor <5 kŮ). EMG signali prikupljali su se pri frekvenciji od 1000 Hz, zatim je za svih pet odriva iz istog početnog položaja određena prosječna mjera, a signal je izglađen (obrađen s pomoću niskopropusnog filtra, granična frekvencija 10 Hz). Iz o vremenu ovisnog EMG signala izvedena je proporcionalna vrijednost mišićne aktivacije (Enoka, 1994) pojedinog mišića, koja se kretala u intervalu 0-1. Izračun vrijednosti mišićne aktivacije za VAS dobiven je kao prosječna vrijednost za mišiće m. vastus medialis i m. vastus lateralis.

Opis modela. U istraživanju je korišten dvodimenzionalni matematički model ljudskog tijela, kod kojega su mišićne sile predstavljale generatore gibanja. Model se sastojao od četiri kruta jednodimenzionalna segmenta (oba stopala – lijevo i desno, u daljnjem tekstu samo 'stopalo', oba koljena - u daljnjem tekstu samo 'koljeno', oba bedra - u daljnjem tekstu samo 'bedro', i 'trup'), gibljiva samo u sagitalnoj ravnini. Model pojedinog mišića bio je pojednostavljen u najvećoj mogućoj mjeri. Mišić je opisan kao jednodimenzionalna veza bez mase, koja je jednostavno generirala silu između dviju točaka, u kojima se spajala na kosti. Točke hvatišta mišića na kost bile su određene s obzirom na anatomske podatke Bobberta i Huijinga (1990).

Lagrange-Eulerove jednadžbe i relativni izvodi. Kretanje tijela moguće je opisati uz pomoć Lagrange-Eulerovih jednadžbi. Postoje dvije jednadžbe kojima je sustav moguće opisati uz pomoć dvije varijable, tj. generalizirane koordinate. Te dvije koordinate predstavljaju kut između horizontalne osi i stopala te između horizontalne osi i koljena. Kako bi se utvrdile uloge mišića u kretanju, iz dviju izvedenih jednadžbi najprije je bilo potrebno izraziti silu potiska na odrivnu ploču, koja je po Newtonovu zakonu izravno povezana s ubrzanjem težišta tijela. Količina na osnovi koje je bilo moguće utvrditi pojedine uloge mišića u kretanju određena je kao parcijalni izvod sile potiska u svakoj od šest mišićnih aktivacija (u daljnjem tekstu 'izvod'). Izračunati izvodi ovise o parametrima modela i parametrima njegove kinematike te predstavljaju neposredne pokazatelje u kojoj mjeri određeni mišić utječe na povećanje ili smanjenje sile potiska u svakom trenutku odriva. Pozitivni izvod poklapa se s agonističkom, a negativni s antagonističkom ulogom pri odrivu, s time da se kao apsolutna vrijednost izvoda opisuje osjetljivost odrivne sile na aktivaciju određenog mišića.

REZULTATI I RASPRAVA

U sva tri početna odrivna položaja dostignute su gotovo jednake završne brzine (neposredno prije nego što se je tijelo počelo zaustavljati). Time je omogućena usporedba odrivne sile i vremenskih parametara odriva. Dobivene su značajne razlike mišićnih aktivacija. U sva tri odrivna položaja najveća je aktivnost zabilježena za mišiće VAS, RF i GLU, a najmanja za BF. Dobivene su znatno veće razlike izvoda za svaki od šest mišića. Izvodi svih mišića, osim izvoda za mišić BF, bili su u ukupnom vremenskom trajanju za sve odrazne položaje pozitivni. To znači da bi smanjena mišićna aktivacija mišića BF proizvela veću odrivnu silu u svakoj fazi odriva. S obzirom na vremenski tijek svih šest izvoda, najviše se ističe odriv iz trećeg početnog položaja (maksimalno pogrčena koljena), dok u ostala dva početna položaja na kraju faze odriva vrijednost izvoda za mišiće VAS, GLU i RF raste, a za mišić BF opada.

Najznačajnije razlike u ovom radu pokazale su se u području osjetljivosti odrivne sile na aktivaciju mišića. U odrivu iz ležećeg položaja mišići VAS, GLU, RF i GAS imaju ulogu agonista, dok je mišić BF antagonist. Svako povećanje aktivacije mišića BF za posljedicu ima smanjenje mišićne sile u svakom trenutku odriva u svakomu od tri početna položaja. Od navedenih početnih položaja, prvi i drugi su se pokazali kao ponajvećma ergonomski, dok je treći položaj manje ergonomski. U tom je položaju također utvrđena najveća osjetljivost gibanja na mišićne aktivacije. Također se pokazalo da se u 3. položaju valja koristiti drugačijom strategijom mišićne aktivacije nego u 1. i 2. položaju, u kojima su uloge mišića gotovo jednake, pa je moguće zaključiti kako u pozadini vjerojatno leži korištenje istog motoričkog programa. U odrivu iz 3. položaja utvrđen je zahtjev za povećanom motoričkom kontrolom i to uslijed veće osjetljivosti gibanja na mišićnu aktivaciju. Zbog toga je bilo moguće zaključiti kako pojedini mišić nije imao ni agonističku ni antagonističku ulogu, već je djelovanjem na sva tri zgloba pridonosio radu poluge ili kao fleksor ili kao ekstenzor. Pokazalo se da je svaki mišić u dva zgloba ekstenzor, dok je u jednom fleksor, ili pak da je u dva zgloba fleksor, a u jednom ekstenzor.

Zbog prisutnosti određenih stereotipnih, u ovom primjeru odrivnih uzoraka mišićne koordinacije, manji odmaci od poželjnih i više ergonomskih početnih odraznih položaja ne narušavaju uzorak mišićne aktivacije. Gotovo jednako dobra učinkovitost odriva postiže se iz prvog i drugog položaja, dok se iz 3. položaja učinkovitost povezuje sa slabijom kontrolom pokreta. Vrijednosti izvoda na početku odriva su u početnom položaju mišića VAS, GLU i RF približno tri puta veće u usporedbi s vrijednostima u 1. i 2. položaju. To bi značilo da već i manji otkloni od vrijednosti aktivacija (i posljedičnih sila) navedenih mišića uzrokuju velika odstupanja u potisnoj sili skupa poluga, te uzrokuju odstupanja od idealnih trajektorija kretanja. Posljedičnu dopunsku kontrakciju u pojedinim zglobovima slijedi smanjena učinkovitost kretanja i veća potrošnja energije. Izvod odrivne sile prema aktivacijama mišića može biti kriterij za utvrđivanje intervala onih odrivnih položaja unutar kojih opći koordinacijski obrazac dovodi do učinkovitog odriva/odraza, kod kojeg je kontrola pokreta visoka, te je značaj mehanizama periferne povratne informacije relativno nizak (Van Soest i Van Ingen Schennau, 1998).

ZAKLJUČAK

Istraživanjem su utvrđene uloge šest mišića pri odrivu iz ležećeg položaja. Mišić BF je imao ulogu antagonista, dok su ostali ispitivani mišići, VAS, GLU, RF, SOL i GAS, agonisti. U svim odrivima na kraju pokreta zabilježena je veća osjetljivost na kontrolu pokreta, nego na početku odriva. Drugi rezultat istraživanja kaže da je osjetljivost na motoričku kontrolu veća što je početni odrivni položaj manje ergonomski. Na temelju tih nalaza moguće je zaključiti kako je kretnju puno lakše kontrolirati na početku pokreta te iz raspona početnih položaja koji bi se mogli označiti kao više ergonomski. Na taj način ljudsko tijelo u gotovo beskrajnom spektru motoričkih akcija čuva visoku učinkovitost kretanja uz pomoć manjeg broja motoričkih programa.

Ključne riječi: *mišićna aktivacija, koordinacija, agonist, odriv, motorička kontrola*