HOW CAN DYNAMIC RIGID-BODY MODELING BE HELPFUL IN MOTOR LEARNING? - DIAGNOSING PERFORMANCE USING DYNAMIC MODELING

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Abstract:

There are two main problems for biomechanists in motor learning practice. One is theory vs. experience, the other is the determination of dominative information directly helpful in the practice. This project aimed at addressing these problems from a quantitative aspect by using motion capture and biomechanical rigid body modeling. The purposes were to identify differences in the description of movements amongst motion analysists (external view), athletes (internal sight) and coaches (internal sight from external view; Lippens, 1997) and to identify applicable and germane information for the practitioners. A trampoline skill of a *vertical takeoff and landing on the back* was selected for the project. The skill was captured and modeled using a five-segment model: head-trunk, arm, thigh, shank and foot. Through the application of dynamic and inverse dynamic analysis, timely variations in joint angles and muscle moments (shoulder, hip, knee and ankle) were calculated to determine description differences among the three views and seek a possible linkage within them. Results show that the inertial and non-inertial systems as well as the coupling of body segments established the differences among the three views and that joint rotations are not identical with the muscular moments, therefore, passive rotations (McGeer, 1990) can occur, and lastly, knowledge of muscular moments at "critical" and passive phases should be emphasized during motor learning. It is concluded that biomechanical modeling should be a platform to link all three views and supply a more holistic picture on human motor control.

Key words: *external view, internal sight, passive phase, critical phase, muscular moments, anthropometry*

WIE KANN DIE DYNAMISCHE FESTKÖRPER-MODELLIERUNG BEIM MOTORISCHEN LERNEN BEHILFLICH SEIN? - LEISTUNGSDIAGNOSE MIT HILFE DER DYNAMISCHEN MODELLLIERUNG

Zusammenfassung:

Im Prozess des motorischen Lernens befassen sich die Biomechaniker mit zwei Hauptproblemen. Das erste Problem liegt in der Theorie gegenüber Praxis und das andere in der Bestimmung der dominanten Information, die in der Praxis nützlich ist. Die Absicht dieses Projekts war es, diese Probleme quantitativ anzugehen, mit Hilfe der Bewegungserfassung und der biomechanischen Festkörper-Modellierung. Damit wollte man die Unterschiede bei der Bewegungsbeschreibung zwischen den Bewegungsanalysten (die äußere Sicht), den Sportlern (die innere Sicht) und den Trainern (die innere Sicht aus äußerem Betrachtungspunkt; Lippens, 1997) bestimmen und anwendbare und relevante Informationen für die Sporttreibenden sammeln. Der Trampolinsprung - *Senkrechte Strecksprung zur Rückenlage* - wurde für das Projekt ausgewählt. Der Sprung wurde gelehrt und nachgeahmt nach einem fünfteiligen Modell: Kopf-Rumpf, Arm, Oberschenkel, Unterschenkel und Fuß. Die dynamischen und inversen dynamische Analysen wurden angewandt und dadurch zeitliche Variationen in Gelenkwinkeln und Muskelmomenten (Schulter, Hüfte, Knie und Gelenk) berechnet, um die Beschreibungsunterschiede zwischen den drei Sichten zu bestimmen, und nach einer möglichen

Verbindung zwischen ihnen suchen. Den Ergebnissen nach liegt der maßgebende Unterschied zwischen den drei Betrachtungsweisen sowohl in Inertialsystemen als auch in Nicht-Inertialsystemen, sowie in der Verbindung der Körpersegmente. Die Gelenkrotationen sind mit den Muskelmomenten nicht identisch, weshalb passive Rotationen (McGeer, 1990) aufkommen können. Letztlich soll man im Prozess des motorischen Lernens Nachdruck auf die Kenntnis von Muskelmomenten in "kritischen" und passiven Phasen setzen. Daraus kann gefolgert werden, dass biomechanische Modellierung eine Plattform dafür sein sollte, alle Sichten zu verbinden und dadurch das holistische Bild von der menschlichen motorischen Kontrolle zu gewinnen.

Schlüsselwörter: *die äußere Sicht, die innere Sicht, die passive Phase, die kritische Phase, Muskelmomente, Anthropometrie*

Introduction

The application of biomechanics in motor learning is already decades old (Hay, 1993; Miller, 1979; Nicol, 1987), but there are still gaps between researchers and practitioners. There are two main problems. One is the communication disturbance between motion analysists and coaches and athletes (theory vs. experience). The other is an understandable predicament in technique analysis utilizing motion-analysis parameters. Motion analysis supplies a vast amount of information, such as force, moment, acceleration, etc. Such information is not a control signal of a movement; therefore, belongs to the indirect criteria, which require in-depth analysis in order to determine their relationship to the desired motor control. Whether coaches and athletes can understand such information and transfer the knowledge into practice, is an enormous uncertainty. Even for motion analysists, there are considerable problems due to the redundancy of the information.

From a biomechanical point of view, there are three aspects, which entail attention, when learning a sport skill: "anthropometrical biomechanics", "biomechanics of performance" and "preventive biomechanics" (Ballreich, 1996). These aspects have the following meanings for the fields of motor learning. The first aspect deals with transfer possibilities. It determines if a skill could be transferred from one bio-geometrical system to another. The second provides a means to describe and generalize movements. Using this, characteristics of a motor skill can be described. Such quantification is needed to direct attention of learners in order to make motor learning more efficient. The third studies the biomechanical load and shows if the load allows a successful learning without possible injuries. Whether these aspects can be successfully applied in sport practice depends on the communication between motion analysists and athletes and coaches. Motion analysists employ quantitative measures to describe a movement in the coordinate system, (which is) fixed to the environment. This digitized outer characterization is considered as *External View* of a motor skill. Since athletes control their muscles in a system fixed to their body, their description of a skill is based on neural control experience, which is known as *Internal Sight* of a skill. With years of experience, coaches should be able to translate a visible movement from the environment system into muscle control information in the body system. Such a translation is called *Internal Sight from External View* (Lippens, 1997). Practice shows that there are some communication disturbances between these systems. The aims of this study are: 1) to identify distinctions between these systems in order to improve the communication, 2) to study interactions of body segments and their influences on motor control and learning in order to illustrate the causes for the communication barriers, and 3) to find relevant and easily applicable information to increase the communication efficiency. For achieving the above purposes, a platform is needed for unifying the interpretations from the three views. Biomechanical modeling has the potential to serve as the nexus.

Methods

The analysis was done in two parts. The first was biomechanical modeling of a vertical takeoff on a trampoline without angular momentum and a landing on the back (Figure 1, (a)). The skill is characterized by the fact that the alteration of the trunk angle during the airborne phase is not caused by an angular momentum. The second part was identifying the influence of each parameter through model simulations and inverse dynamic analyses.

Model Construction

A 2-dimensional 5-segment rigid body model was constructed (Figure 1, (b)) consisting of arms,

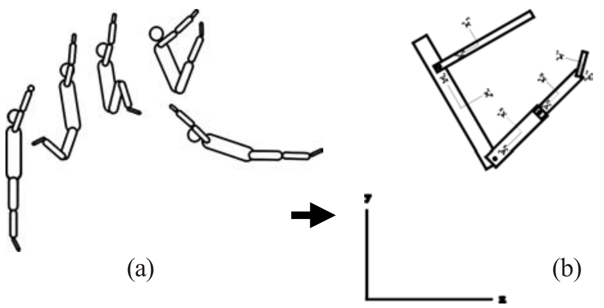


Figure 1. (a) A trampoline skill - vertical takeoff and landing on the back. (b) The 2D 5-segment rigid body model of the skill.

head & trunk, thighs, shanks and feet. The model has 7 degrees of freedom (DOF) and works on the basis of Lagrange's dynamics. The software package DADS (Dynamic Analysis and Design System, Haug 1989) was utilized for model calculation. The program allows one to perform dynamic and inverse dynamic analysis, enabling the calculation of the net joint moments and net joint muscle moments. The model required both anthropometrical and kinematical data. Anthropometrical data was measured directly by utilizing the body-profile method (Shan, 1993; Shan & Nicol, 1995), while those used in model simulation were estimated by multiple regression equations (Shan & Bohn, 2003). Zatsiorsky's human body model (1983) was utilized to define the segmental borders. The two parameters employed for estimation of anthropometrical data were body weight and height. The kinematical data for model construction were measured from a well-trained sport student who performed the airborne movement. Measurements of shoulder joint, hip joint, knee joint and ankle joint as well as three initial conditions (vertical velocity of centre of gravity - CG), absolute trunk angle and trunk angle velocity) were done using a Video Movement Analysis System (OrthoData Ltd.). These seven kinematic variables formed the 7 DOF used in the constructed model.

Analysis and Identification

In relation to the aims of the study, the following biomechanical analyses were conducted.

- Joint angle and joint angle velocity are usually utilized to describe the skills in the external view, whereas net joint muscular moment supplies the joint rotation control signal in the internal sight. In practice, external view is usually identified as effects and internal sight as causes. The cause-effect relationship is often validated by Newtonian dynamic equation (e.g. $\vec{M} = \frac{d}{dt}(J\vec{\omega})$, where M is net muscle moment and w angular velocity), namely muscle activity causes joint rotation. Therefore, by evaluating the angle velocities and muscle moments using Newtonian equation, we could determine if external view and internal sight are identical.
- The influence of anthropometrical data – different body structure (e.g. tall vs. short, heavy vs. light) – on the change of the trunk angle was studied by simulation. The goal was to observe to what extent the anthropometry affected the movement. This exploration is directly related to the translation of a skill by coaches with different body structure - internal sight from external view. In other words, how does anthropometry affect the coach's experience (i.e. his/her motor control)?
- Alternative joint rotations were simulated to determine critical phases. Critical phases are those in which even a slight deviation could lead to entirely different results. In addition, joint simulations were also applied to develop alternative (new) skills.
- Joint, physical (gravity, centrifugal force, etc.) and muscular moments during the movement and landing positions were also analysed using individual anthropometrical data and inverse dynamic analysis so as to supply control information for simplifying learning or for estimating internal load to prevent possible injuries.

Results

The characteristic of the skill is the alteration of trunk angle without an applied angular moment. Therefore, in order to examine the accuracy of the model, the measured and calculated trunk angle vs. time were compared (Figure 2). The error rate of 6% was small enough for analysis and simulation. Thus, we employed this model to carry out the following simulations as well as analyses.

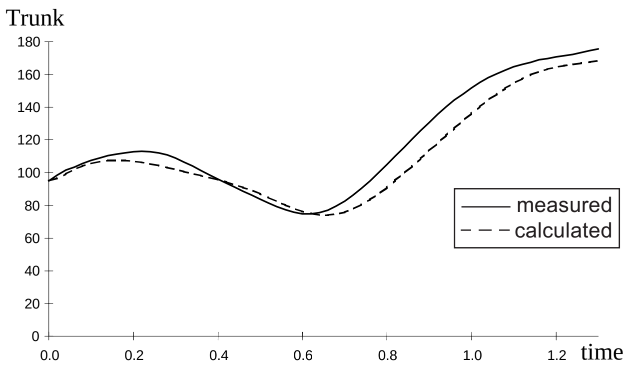


Figure 2. Comparison of the measured and calculated trunk angles vs. time.

First, the results of dynamic and inverse dynamic analyses depicted that the correlations of joint angular velocity, joint moments and joint muscle moments are low or non-existent. Figure 3 reveals that from 0.16 -0.42 s the muscle moment in the knee joint can be neglected, while the angular velocity changes significantly. This indicates a passive rotation in which the joint rotation happened with hardly any muscle control. A passive movement is the movement that happens without any control and energy supply. The phenomenon was proved by physics modeling (McGeer, 1990).

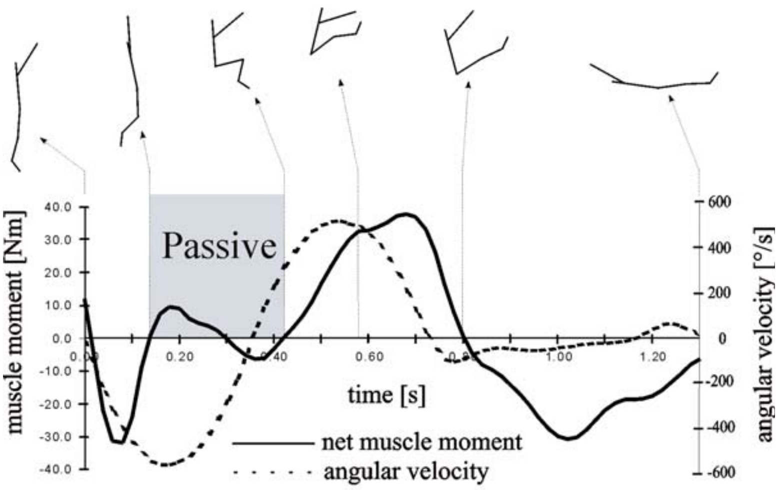


Figure 3. The dynamic and inverse dynamic analysis of the knee joint.

The opposite situation to passive phase can be seen from 0.9 - 1.2 s in Figure 3, i.e. large muscle moment with hardly any joint rotation. In this phase, huge muscle moment is needed just for the fixation of the joint.

The second result of this research was the influence of anthropometrical data on the airborne movement. With the purpose of determining the influence of the anthropometry on the aerial phase of the skill, four body types were utilized in the simulation. The four body types were male Chinese, female Chinese, male German and female German. Shan and Nicol (1998) showed that:

- Germans were in average 15 kg heavier and 9 cm taller than Chinese, and
- for the same body weight and height, Chinese have bigger heads, longer trunks as well as shorter legs and arms in comparison to Germans.

Hence, the influences were examined using absolute and relative differences. For the absolute case, anthropometrical data of a Chinese woman (1.55 m, 46 kg) and a German woman (1.70 m, 65 kg) were compared using the same joint rotation. Results demonstrated that the change in trunk angle of the small Chinese women (181°) was greater than that of the German woman (169°). In the landing phase, the trunk angle of the Chinese woman was greater than 180°, which means landing on the head. So for the prevention of injury, joint rotations must be changed.

In order to study the influence of relative differences in the anthropometrical data, four groups were chosen: a Chinese man and woman, and a German man and woman. The anthropometrical data were calculated using the same body weight (65 kg) and body height (170 cm). The simulations exposed little influence caused by the relative differences on the airborne movement. The differences amongst trunk angle of the four groups were within 4° (169°-173°). According to these results, the influence of anthropometry on the airborne movements, such as differences of coaches' control experience (internal sight from external view), is mainly affected by body height.

The subsequent results of the research focused on possible new skills or critical phases. Critical phase is one in which a small divergence in performance will result in a totally different movement. The model simulations were utilized to reveal the possible new skills or the critical phases, which should be emphasized in the learning process. We did the simulations from one joint to another by varying a joint's rotation while keeping the others unchanged.

The first simulation was with the shoulder joint. We changed the pattern of arm rotation to see whether a new skill is possible. The simulation (Figure 4) illustrated that rotating the arm clockwise or counter-clockwise makes landing on the back possible. Only few individuals could perform such skills because of anatomic conditions in the shoulder joint. In addition, the skill performed with clockwise arm rotation is dangerous due to the landing. It was unfortunate that we did not find a capable subject willing to attempt the skill with backward arm rotation.

The hip simulation was done by omitting the hip over-extension at the beginning of the performance. A very critical phase was found in the simulation, namely the over-extension of the hip joint. A straight, not over-extended hip (Figure 5 (a)) leads to landing on the feet (Figure 5 (b))

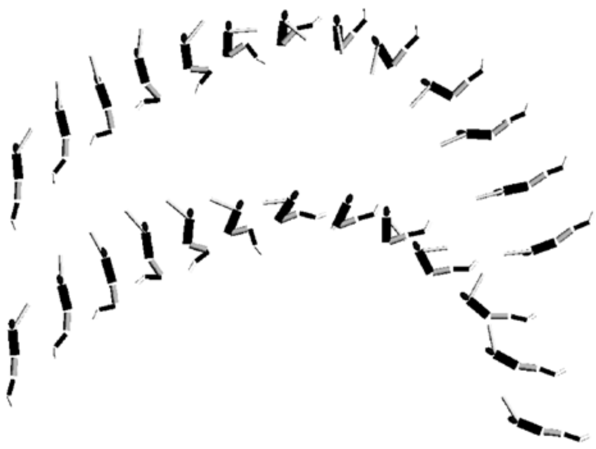
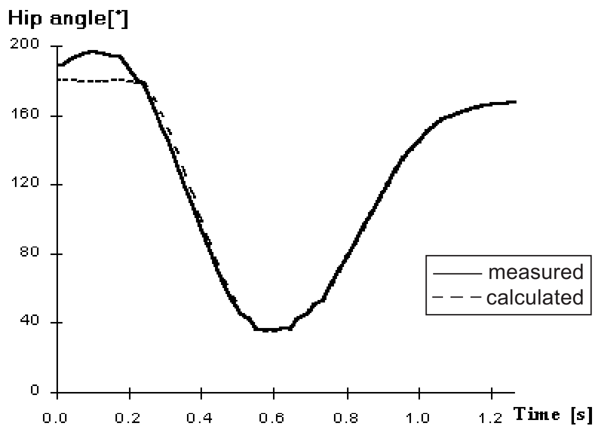
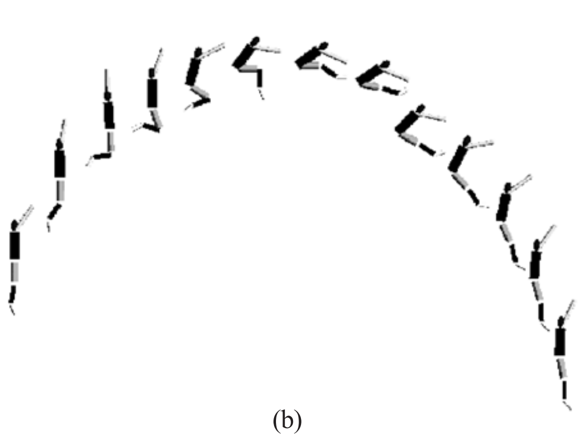


Figure 4. Variation of the arm movement - two possible new skills.

instead on the back. This control error (neglecting the over-extension of hip at the beginning) is often seen during practice. Therefore, the control of the hip movement at the beginning must be emphasized in order to achieve successful learning.



(a)



(b)

Figure 5. (a) Variation of the hip movement. (b) Without the hip over-extension at the beginning, the skill turns out as a "pike".

The knee simulation was to change the passive rotation into active rotation, i.e. active knee flexion in the passive phase. This unnecessary control pattern is often observed in amateur learners using only kinematical information. Without inverse dynamic analysis, one cannot be sure whether the rotation is passive or active. The typical judgement is that the segment rotation is active, because the muscle moment causes the rotation of the segment. The simulation confirmed another critical phase, which was also present in the learning period. In the first try, a competent student, who performed the skill with active knee control in the passive phase, had the feeling that her whole body rotated backwards, which is theoretically impossible because of the zero momentum. However, the simulation after her control pattern shows that her feeling, which was mainly based on her trunk and leg movement, was correct, but only within a very limited time period (Figure 6, highlight area). The momentum of the whole body was still zero. Because of this short period, due to the fear of injury she began the protectoral adjustment. As a result of this failed attempt, fear impeded subsequent trials (learning).

Finally, the internal load analyses (load to muscle and joint) revealed that the maximal muscle load (found in the hip joint) was about 2.5 times the load in the leg-up movement (Ahonen, 1994). Which means, there should be no overload for the muscle. In comparison with the running model (Natrup, 1996), the load on joints in the skill is much smaller than that in running. There should also be no overloads. So the only risk factor of the skill is landing position, which could be determined by model simulation using individual anthropometrical data and should-be-learned kinematics. Taken together, we could conclude that the control signal of the skill in a safe performance is dependent on body height. Different heights should employ different control signals.

Discussion and conclusions

Passive movement

McGeer (1990) utilized a physics model to demonstrate a walk without control and energy supply – the phenomenon of passive movement. Although a total passive movement (or sport skill) in reality is rarely observed, some phases of a skill could be passive, such as the passive rotation phase in this studied skill. This passive movement diverges the (control) sensation of an athlete from

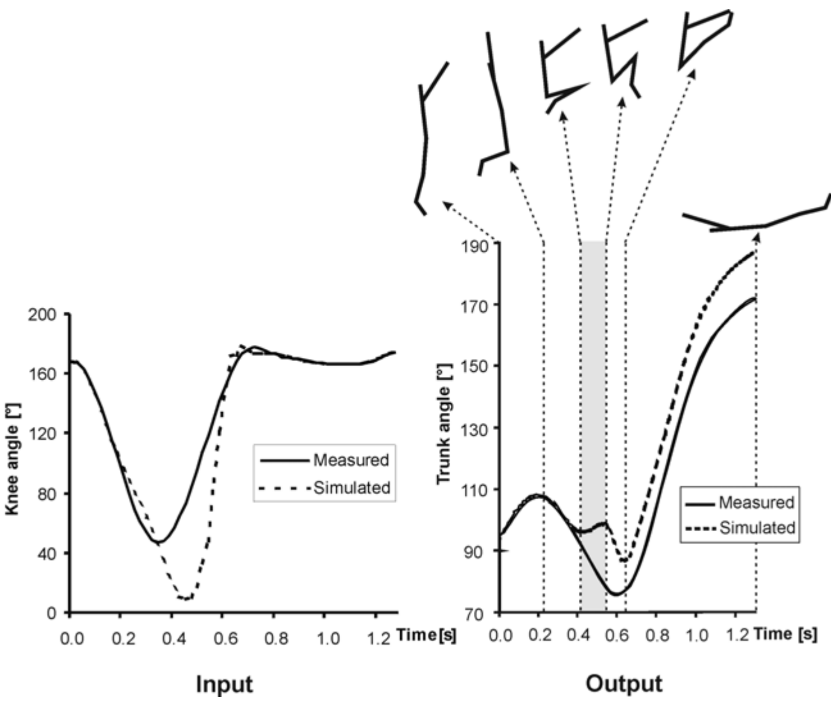


Figure 6. A critical phase caused by using visual information only in the learning - active knee rotation in passive phase.

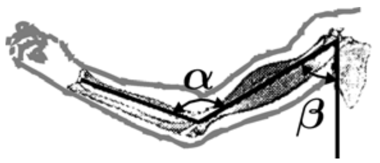
the theory explanation. Obviously, such phases can only be determined by muscle moment analysis (inverse dynamic analysis). The advantage of the passive phenomenon in motor learning is the simplification of the motor control by neglecting the control in passive phases.

The control simplification is a classical problem in motor learning, which is known as the degrees-of-freedom problem (Bernstein 1967, first published 1940, Kelso, 1984; Turvey, 1990). Bernstein believed the simplification of motor control is done by the reduction of degrees of freedom and not as many of the traditional views of motor control and information processing states, which is that subjects must directly control the many degrees of freedom in the human body with the intention of producing coordinated movement. His proposal has been tested and implemented in numerous studies (Schmidt, 1975; 1976; Turvey, 1977; 1990) in the motor control and biomechanics domains. Shea and Wright (1997) summarized the researches as specific muscles to be identified, the actual force, and actual timing of the control to be emphasized so as to reach the simplification. Identification of passive phases through inverse dynamic modeling supplies a quantitative way to reach this goal.

External view vs. internal sight

As it is known, the dynamic relation between joint angular rotation and joint muscle moment (the control feeling of athletes – internal sight) is often misinterpreted by incorrectly using the Newtonian equation $\vec{M} = \frac{d}{dt}(J\vec{\omega})$, which states muscle moment as the cause of segmental rotation. Such misinterpretation is taught in sport biomechanical courses at universities to give the theoretical basis for observing and analysing a movement (external view). In fact, the relationship between joint angular velocity and muscle moment is so complicated that no one can predict it, unless one utilizes the calculation of system dynamics (inverse dynamic modeling). Therefore, the external view, resulting from the movement analysis (without inverse dynamic modeling) based on a captured motion, will not supply the actual internal sight. This study supports this view. The results of the dynamic and inverse dynamic analyses in this research showed that such a proportional relation between segmental rotation and muscle moment hardly existed in the aerial movement. The *raison d'être* for this deviation between joint rotation and muscle activity are: (a) non-muscular forces such as gravity and inertial forces (centrifugal force, Coriolis force, etc.) and (b) influence of structures in the neighborhood (physics chain effect). Figure 7 (a) shows an example of the influences of a non-muscular force (gravity) on the muscle moment. The influence depends largely on the segmental position. For example, if an elbow extension remains the same (e.g. from 90° to 180°) when the arm is abducted at 0°, 90°, or 180° position, very distinct muscle moments are needed to execute the same elbow extension. Generally speaking, the influence of non-muscular forces (gravity and inertial forces) depends on the movement conditions of a system. The senses of an athlete are established in his/her body system, which is in most cases, a moving, non-inertial system. In fact, early in the 1930s, Bernstein (1967) realized the interaction between muscle forces and external forces (he called the external forces passive forces) and proposed that part of learning a skill is learning how to take advantage of passive forces. However, Bernstein did not become conscious of the passive movement.

(a)



α: from **90º** to **180°**

1) β= 0°, $M_{MUSCLE-1}(t) = 0$

2) β= 90º, $M_{MUSCLE-2}(t) = M_G(t)$

3) β= 180°, $M_{MUSCLE-3}(t) > M_G(t)$

(b)

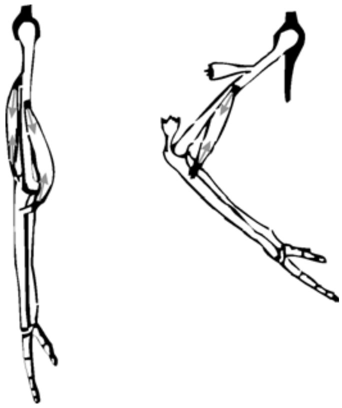


Figure 7. (a) The influence of non-muscular forces on muscle moment. M_{MUSCLE}: muscle moment; M_G: the moment of gravity of the lower arm. (b) The passive shoulder rotation caused by elbow flexion - physics chain effect.

Figure 7 (b) represents an example of the influence of structures in the neighborhood using an arm model with only one elbow extensor and one elbow flexor. It is assumed that the system has the following initial conditions, extensor force is equal to the flexor force and that the shoulder rotation axis is fixed in space and no arm movement occurs. If the elbow extensor is cut off, a rotation of the shoulder joint will occur without applied moment. It is obvious that the passive rotation of the shoulder joint is caused by the rotation of the elbow joint (physics chain effect). This also illustrates the reason for a non-proper movement of a segment often lying within neighboring segments.

In conclusion, the difference between movement and muscular moment, such as the difference between external view and internal sight, is caused by the incompatibility between inertial and non-inertial systems and the interaction between neighboring segments. In other words: the description (for example: impulse = Δ momentum or $\vec{M} = \frac{d}{dt}(J\vec{\omega})$) in the inertial system, which is the system of a spectator, is invalid and unsuitable for the non-inertial system in which the athlete controls his/her movement.

Internal sight from external view

Since everyone accumulates performance experience based on his/her own body system, the translation of a visual movement into motor control signals (internal sight from external view) will naturally be affected by one's body type. The simulations in this research revealed the significance of body height in militating airborne movements. The results indicate that the coaches' experience as well as the motor control of movements is affected by body height. This might have two consequences:

(a) Coaching of the motor control of a skill needs to be adapted to the anthropometrical data of the athlete. In practice, we often encounter numerous failed attempts at a certain complex skill, that one cannot do it after so many times of practice. One reason could be that the experience (motor control) of a coach does not suit an athlete's body type.

(b) Coaching literature should not be simply translated into foreign languages but it should also be adapted to significant differences in the anthropometrical data of the average athlete in different countries.

Critical Phases

In the dynamic simulations, two critical phases were confirmed. The first one was the hip over--extension at the beginning of performance. Because of its short duration, most learners do not pay attention to it. That is why 35% (n=20) of the students in a trampoline course at the University of Muenster failed in self-learning of the skill by using visual information. Such a learning error for beginners can be avoided by letting the students see the dynamic simulation. The second critical phase is the active knee rotation in the passive phase. Obviously one cannot confirm the passive phase without inverse dynamic analysis. Therefore, the dynamic and inverse dynamic analyses of a skill can reveal the dominant aspects, which could not be achieved by using visual information only (which is unfortunately the most widely used method in teaching or training), and help the learner to establish their proper motor control of the skill from the beginning of the learning process.

Using biomechanical modeling, this study reveals that: 1) the difference between joint kinematics and muscular control, as such the difference between external view and internal sight, is caused by the difference between inertial (fixed to environment) and non-inertial (fixed to a movement body) systems plus the interaction between neighboring segments, 2) passive rotations can occur because of the influence of non-muscular forces and the physics-chain-effect, and 3) trainer's experience – the translation of vision movement into neural control process (the internal sight from external view) – will be affected by one's body height. These results suggest that dynamic modeling is a potential platform for minimizing the communication disturbances between motion analysists and athletes and coaches, and could lead to efficient motor learning by identifying critical and passive phases. Such an approach is no doubt a nexus to link and unify the interpretations from practitioners' experience and theoretical analyses.

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KAKO DINAMIČKO MODELIRANJE TIJELA KRUTIM SEGMENTIMA MOŽE POMOĆI U MOTORIČKOM UČENJU?

Dijagnostika pokreta pomoću dinamičkog modeliranja

Sažetak

Uvod

Praktičari u sportu obično se u primjeni analize pokreta i biomehaničkog znanja u području motoričkog učenja susreću s dvije vrste problema. Jedan je suprotstavljenost teorije i iskustva, tj. udaljenost dobivenih rezultata analize/teorijskih predviđanja i iskustva/'osjećaja kontrole'. Drugi se odnosi na određivanje dominantne informacije koja izravno pomaže učenju motoričkih vještina. S biomehaničkog gledišta postoje tri aspekta koje treba uzeti u obzir: 'antropometrijska biomehanika', 'biomehanika pokreta' i 'preventivna biomehanika'. Antropometrijska biomehanika bavi se mogućnošću transfera vještina iz jednog bio-geometrijskog sustava u drugi. Biomehanika pokreta opisuje karakteristike pokreta s ciljem da utvrdi dominantne informacije o učenju. Preventivna biomehanika proučava biomehanička opterećenja i pokazuje može li opterećenje omogućiti uspješno učenje bez opasnosti od ozljeđivanja. Hoće li ti aspekti biti uspješno primijenjeni u sportskoj praksi, ovisi o komunikaciji među istraživačima koji analiziraju pokret, s jedne strane, i sportaša i trenera, s druge. Na temelju kinematičkih mjerenja gibanja u prostoru, istraživači koji analiziraju pokret opisuju kretanje u koordinatnom sustavu fiksnom u odnosu na okolinu (*vanjsko gledište*). Međutim, sportaš/sportašica kontrolira svoje mišiće u sustavu fiksnom u odnosu na njegovo/njezino tijelo (*unutarnje gledište/unutarnji dojam*). Postoji, međutim, i treći izvor informacija. Na temelju dugogodišnjeg iskustva, trener može prevesti opaženi pokret iz okoline u područje mišićne kontrole u tjelesnom sustavu (*unutarnje gledište iz vanjske perspektive*) (Lippens, 1997). Praksa, međutim, pokazuje da postoje neke komunikacijske poteškoće između sustava koje su uzrokovane različitim objašnjenima proizašlima iz različitih gledišta, a to remeti efikasnost motoričkog učenja u praksi. Ovaj rad pristupa tom problemu na kvantitativan način koristeći kombinaciju kinematičkih mjerenja gibanja u prostoru i modeliranja tijela krutim segmentima.

Vještina skakanja na trampolinu, točnije sposobnost vertikalnog odraza i doskoka na leđa, odabrana je za analizu u ovom radu. Svrha prvog dijela istraživanja bila je utvrditi razlike u opisu kretnji s obzirom na vanjsko gledište, unutarnje gledište/dojam te unutarnje gledište iz vanjske perspektive. Svrha drugog dijela bila je, na temelju tih spoznaja, identificirati informacije koje će biti korisne vježbačima u praksi.

Metode

Poznato je da se kinematičko mjerenje gibanja u prostoru i modeliranje tijela krutim segmentima može koristiti kako bi se utvrdile najvažnije karakteristike kontrole zglobova pri izvođenju vještine koja se promatra. Na temelju kinematičkih parametara moguće je utvrditi promjene položaja zglobova u vremenu. Koristeći se osnovnim pravilima fizike, možemo jednostavne podatke o položaju prevesti u termine modelnih pokreta krutih segmenata tijela. Za potrebe ovog rada konstruiran je model od pet segmenata: glava-trup, ruka, bedro, potkoljenica i stopalo za izračunavanje kutova u zglobovima ramena, kuka, koljena i gležnja. Dobivene vremenske varijacije u kutovima tih zglobova često se koriste u okviru kinematičke analize pokreta za utvrđivanje karakteristika pokreta i obrasca njegove kontrole (*vanjsko gledište*).

Kako bi se provela temeljita analiza, u ovom je radu korišteno inverzno modeliranje za utvrđivanje mreže momenata zglobova i mišića, što je kvantitativna vrijednost za grupni učinak rada zglobno-mišićnog sustava. Ta varijabla je unutarnji uzrok za pokretanje zglobova i trebala bi biti čvrsto povezana sa sportaševim 'osjećajem kontrole'. Tako se izračunata mreža momenata mišića može koristiti kao reprezentant unutarnjega gledišta. Ako se promjena u kutu pokreta zgloba i momenta mišića može objasniti Newtonovom dinamičkom jednadžbom, koja se koristi u kinematičkoj analizi sila i momenata gibanja u prostoru, tada bi se vanjsko gledište moglo izjednačiti s unutarnjim.

U izračunavanju parametara modeliranja, parametri inercije tijela (jedna vrsta ulaznih podataka) procijenjeni su uz pomoć antro-

pometrijskih 'normi' dobivenih u statističkim studijama (Zatsiorsky i Seluyanov, 1983; Shan i Nicol, 1998). Promjenom antropometrijskih podataka (stas), a uz održavanje kontrole zglobova konstantnom, moguće je uz pomoć modela odrediti jesu li položaji perifernih dijelova tijela jednaki ili ne. Kako je individualno iskustvo pojedinca usko povezano s njegovom/njezinom bio-geometrijskom strukturom, takva modelna simulacija može se koristiti kako bi se istražio utjecaj trenera na objašnjavanje vještine (unutarnje gledište iz vanjske perspektive).

Rezultati i rasprava

Rezultati ovog istraživanja pokazali su da vanjsko gledište, utvrđeno kinematičkom analizom gibanja u prostoru, nije jednako sportaševu osjećaju kontrole (unutarnje gledište). Uzroci tih razlika jesu sile inercije, kao i uzajamno djelovanje segmenata unutar složenog, višesegmentnog sustava (fizikalni efekt lanca). Drugo, rotacije zglobova nisu jednake mišićnim momentima; mogu se pojaviti i pasivne rotacije (McGeer, 1990). Pasivna rotacija je pokret u zglobu koji ne zahtijeva nikakvu kontrolu ni energetsku opskrbu. Prednost pasivnih fenomena u motoričkom učenju leži u pojednostavljivanju motoričke kontrole zahvaljujući mogućnosti da se u fazama pasivnosti kontrola zanemari. Pasivni pokret odvaja sportašev osjećaj (kontrolu) od opisa pokreta koji se temelji na kinematičkim karakteristikama utvrđenima kinematičkim analizama pokreta. Takve (pasivne) faze moguće je odrediti jedino momentom mišića (zgloba) koji se može dobiti inverznom dinamičkom analizom. Treće, individualno je iskustvo pod snažnim utjecajem tjelesne visine. To nas vodi do raznolikih unutarnjih gledišta iz vanjske perspektive. Stoga bi treniranje vještina trebalo biti prilagođeno antropometrijskim obilježjima sportaša. I na koncu, u motoričkom učenju trebalo bi naglašavati poznavanje mišićnih momenata i 'kritičnih faza'. Kritična faza je trenutak u izvedbi u kojoj i minimalno odstupanje kontrole pokreta može dovesti do potpuno drugačijeg ishoda. I opet valja naglasiti da takve faze nije moguće uočiti 'izvana', dok ih se dinamičkom simulacijom može vrlo jednostavno utvrditi.

Zaključak

Može se zaključiti da kinematička analiza pokreta pribavlja informacije o kinematičkim karakteristikama motoričke vještine, međutim, ne može dati uvid u uzročno-posljedične odnose. To uzrokuje razmimoilaženje između vanjskog gledišta i unutarnjega gledišta ili sportaševa dojma. I antropometrijska obilježja utječu na individualno iskustvo, pa su modifikacije u primjeni nužne. Jedan od načina povezivanja vanjskog gledišta, unutarnjeg gledišta i unutarnjeg gledišta iz vanjske perspektive jest i biomehaničko modeliranje ljudskog tijela krutim segmentima.

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