HOW CAN DYNAMIC RIGID-BODY MODELING BE HELPFUL IN MOTOR LEARNING? – LEARNING PERFORMANCE THROUGH DYNAMIC MODELING

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Abstract:

The purpose of this research project was to bridge the gap between motion analysists and athletes and coaches by establishing a platform for the communication amongst the three parties. The first part of this project depicted that: 1) differences amongst the external view (motion analysists), internal sight (athletes) and internal sight from external view (coaches) were caused by the inertial (environment-fixed) and the non--inertial (body-fixed) system; 2) joint rotations were not identical with the muscular moment, therefore, passive rotations can occur; 3) critical phases in a skill control, which can be revealed by using modeling simulation, should be emphasized during learning; and 4) dynamic modeling has the potential to link and to unify the three views and supply a more holistic picture of human motor control. Based on these results, a learning model was constructed in the second part of the project. The essence of the model is to supply learners with the control signal (muscle moments) obtained from individual anthropometrical data and should-be-learned kinematics. Such an individualized learning process consists of: 1) obtaining kinematic characteristics of a should-be-learned skill using motion capture, 2) substituting the model's anthropometrical data with a learner's data, and applying inverse dynamic analysis to the model for obtaining muscle moments – the individualized control signal, and 3) applying the control information in the skill learning. The model was validated in a motor learning study. The study unveiled that dynamic modeling is well suited for improving communication with athletes and coaches as well as for improving efficiency of learning.

Key words: *kinematics, anthropometry, muscular moments, passive phase, critical phase*

WIE KANN DIE DYNAMISCHE FESTKÖRPER-MODELLIERUNG BEIM MOTORISCHEN LERNEN BEHILFLICH SEIN? FERTIGKEITSERWERB MIT HILFE DYNAMISCHER MODELLIERUNG

Zusammenfassung:

Die Absicht dieses Projekts war, die Kluft zwischen den Bewegungsanalysten, den Sportlern und Trainern zu überbrücken, um eine Platform für die Kommunikation zwischen den drei Parteien herzustellen. Im ersten Teil des Projekts wurde klar, dass 1) die Unterschiede zwischen der äußeren Sicht (den Bewegungsanalysten), der inneren Sicht (den Sportlern) und der inneren Sicht aus äußerem Betrachtungspunkt (den Trainern) von (umweltgebundenen) Inertialsystemen und (körpergebundenen) Nicht-Intertialsystemen verursacht sind; 2) dass die Gelenkrotationen mit den Muskelmomenten nicht identisch sind, weshalb passive Rotationen aufkommen können; 3) dass man Nachdruck auf kritische Phasen der Fertigkeitskontrolle während des Erwerbs setzen sollte, was man mit Hilfe der Modellierungssimulation erzielen kann; 4) dass die dynamische Modellierung imstande ist, die drei Sichten zu verbinden und zu vereinigen, um dadurch das holistische Bild von der menschlichen motorischen Kontrolle zu gewinnen. Aufgrund dieser Ergebnisse, wurde im zweiten Teil des Projekts ein Lernmodell entworfen. Der Kern des Modells ist, den Lernenden ein Kontrollsignal (Muskelmomente) zur Verfügung zu stellen, das sich aus individuellen anthropometrischen Angaben und einer noch-zu-erwerbenden Kinematik ergibt. Ein solcherarts individualisierter Erwerbsprozess setzt voraus, dass 1) man die kinematischen Eigenschaften einer zu erwerbenden Fertigkeit mit Hilfe der Bewegungserfassung bestimmt, 2) dass man die anthropometischen Angaben des Modells mit denen des Lernenden ersetzt, und die inverse dynamische Analyse auf das Modell anwendet, um Muskelmomente, bzw. ein individualisiertes Kontrollsignal zu bekommen, und 3) das man die Kontrollinformation beim Fertigkeitserwerb anwendet. Das Modell wurde in der motorischen Lernstudie gültig gemacht. Die Studie zeigte, dass sich die dynamische Modellierung sehr gut eignet, um die Kommunikation zwischen den Sportlern und Trainern zu verbessern, sowie den Lernprozess zu fördern.

Schlüsselwörter: *Kinematik, Anthropometrie, Muskelmomente, passive Phase, kritische Phase*

Introduction

One of the major goals in the study of motor learning is to understand which influential parameters are involved in the maximization of learning (Schmidt, 1988). Therefore, biomechanical researches in motor learning should be focused on this point. One useful approach is to combine objective methods with subjective means (Magill, 2001). Objective methods are related to an external view, whereas the subjective means (experiences) are related to internal sight. Due to the diverse points of view, there are some communication disturbances among coaches, athletes and motion analysists, and the teaching method based on personal experience is widely used. However, the rationale for decisions or the understanding based on personal experiences may differ from one educator to another (Magill, 2001). This concern was confirmed by a quantitative research (Shan, Sust, Simard, Bohn, & Nicol, 2004). Hence, improving the communication amongst coaches, athletes and motion analysists plays an important role in helping motor learning to step out of experience and into an objective and quantitative transaction.

In order to eliminate the communication barriers, the origination of the misunderstandings should be firstly located. The first part of this research project demonstrated that the inertial (environment-fixed) and non-inertial (body-fixed) systems as well as the coupling of body segments established the differences amongst the motion analysists, coaches and athletes. Because of the non-inertial forces and segmental coupling, joint rotations are not identical with the muscular moments; hence passive rotations (McGeer, 1990) can occur. All these facts imply the divergence of the motion analysis description (kinematic characteristics) of a skill and the controling experience of an athlete.

Precedent studies (Bernstein 1967, first published 1940; Schmidt, 1975, 76; Kelso, 1984; Turvey, 1977, 1990) unveiled that simplifying motor learning is actually to discover ways to reduce the degrees of freedom of a skill, which could be reached by supplying the following information to learners: specific muscles to be used, the actual force, and detailed timing of the control (Shea & Wright, 1997). This identifies the recognition of a control pattern and not the kinematic characteristics of a skill as the common base of communication. Unfortunately, the descriptive motion analysis obtained from a motion capture (external view) could not meet the aims. However, the desired control parameters could be derived from dynamic and inverse dynamic modeling. This justifies that dynamic modeling could be a potential avenue to reach the goals. Therefore, the purpose of this study is to apply inverse dynamic analysis into the motor learning practice to see if it could serve as a platform to unify the different views, as such to improve the efficiency of motor learning. It was hypothesized that the abstracted control pattern from the modeling could supply a common basis of communication, link the experience with objective measures and increase the efficiency of learning.

Method

For the purpose of deriving the control signals from a captured skill, dynamic and inverse dynamic modeling should be employed. As suggested, the modeling could also provide modified control signals (internal sight) according to individual anthropometric uniqueness and kinematic characteristics of a skill (external view). Based on this consideration, a flight phase learning model that focuses on a control signal was constructed. The essence of the learning model was a dynamic rigid body model, which supplied the control relevant information to the learners. The learning model consists of two parts: 1) constructing a skill using motion capture and biomechanical modeling in order to receive the control signals of the skill from a professional and 2) adapting the control to an individual learner based on the learner's anthropometric characteristics. The mechanism of the model is illustrated in Figure 1. The model could be applied in two ways: to replicate a skill and to create a new skill. The steps for duplication are as follows:

1. A skill is studied and a dynamic model is constructed by inputting the kinematic and anthropometric data of a master
2. The anthropometric data of a master is substituted with that of a learner so as to check if the skill can be transferred to the learner without overload
3. Critical phases (for emphasizing) and passive phases (for neglecting) are identified.
4. The motor control relevant information such as muscular moments, critical phases and passive phases are displayed to the learner.

The application for creating a new skill is identical to the above procedures with the exception of step two. The alteration of anthropometric data will be replaced by the adjustment of kinematic data (known as model simulation), enabling alternative new or modified skills to be constructed and the related muscle activities and load information could be supplied to the learner in advance.

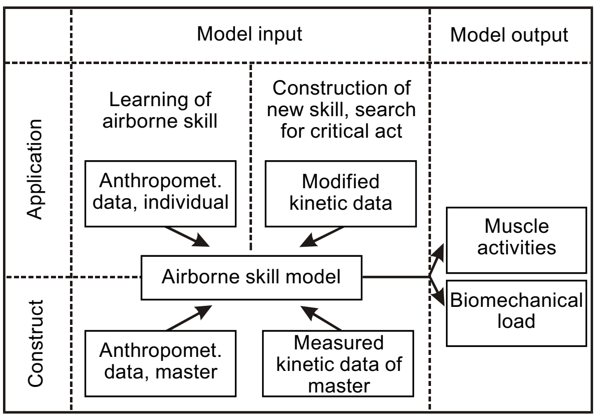

Figure 1. A flight phase learning model based on individual anthropometric data and kinematics.

The model was validated in a learning course at the University of Muenster. Twenty sport students (divided into two groups) participated in the trial. The experiment examined two aspects of learning, namely, knowledge and performance. The first group learned the skill in a conventional way with visual information only (Figure 2). The second group was provided with muscle control information additional to the visible information (Figure 3). The main control pattern and phases obtained from Figure 3 were:

- short extension of shoulder and hip, flexion of knee;
- flexion of shoulder and hip (only two joints necessitate control because of the passive knee rotation);
- extension of all joints; and
- unfolding the body.

After studying the supplied information, each subject was given five chances to practise the skill. Besides the supplied visual information (Figure 2 for the control group and Figure 3 for the experimental group), no other feedbacks were supplied for both groups before or between trials. Each trial was recorded using a video camera for expert evaluation. After five attempts, each subject filled out the Questionnaire part I (Fig. 4). The information sheets were exchanged between the two groups upon the completion of the Questionnaire part I in order to contrast the two methods. Without further practice, Questionnaire part II (Figure 5) was completed and data analyses based on the video and questionnaire were conducted. Because of the independent samples and non-parameter nature of the questionnaire, the U-tests were applied to reveal the differences between the

Figure 2. Learning information for group one (traditional).

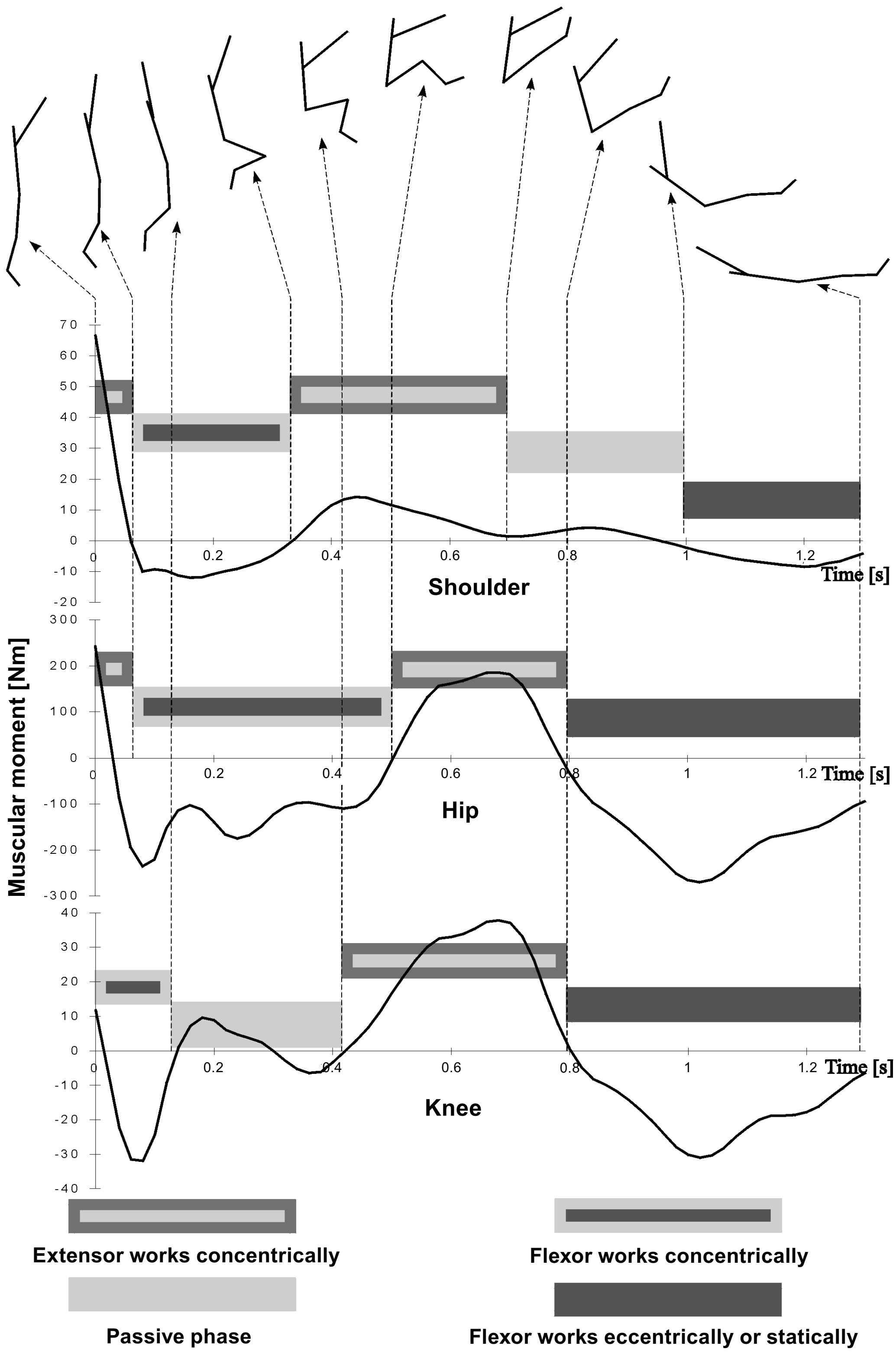

Figure 3. Learning information for group two.

two methods (Fleischer, 1988). For the purpose of judging the successes in learning objectively, all the video recorded material of the attempts were analyzed by experts. The evaluations were executed according to the following criteria:

1) An agreement of the joint controls with the given picture (timely coordination among joints).
2) A deviation from the target movement (the landing position).

With the aim of quantifying the evaluation, the movement execution of each trial was arranged on a scale of 0-10, with 10 representing an outstanding execution.

Results

The experimental outcome proved the method supplying both kinematic and muscle control information to be superior. In the students' opinion, the second method (kinematic and muscle control information) leads to a better understanding of the skill. The subjective knowledge comparison is illustrated in Figure 6. The results revealed that there are significant differences ($p<0.05$) in the mental interpretation of the skill (Q1, Fig. 6), knowledge improvement throughout the trials (Q3, Fig. 6) and accuracy of the estimation of the learning effect (Q4, Fig. 6). Using the muscle

Motor Learning Questionnaire
(Trampoline skill - vertical take-off and landing on the back)
Part I

Classification of scale: Positive numbers define a high self-assessment, while negative numbers represent low self-assessment.
Example: In evaluation #3, a positive number on the rating scale means that the knowledge status is improved by practical attempts, a negative number shows little agreement between the movement conception and movement execution is present.

Name:

Knowledge Evaluation:

1. I can imagine the skill based on the visual information supplied.		-3 -2 -1 0 1 2 3
2. Before movement execution, I have confidence that I am able to complete the movement well.		-3 -2 -1 0 1 2 3
3. Did your movement conception change by practical testing (after one or more attempts)?		-3 -2 -1 0 1 2 3
4. I can estimate exactly how my course of motion corresponds with the visual representation.		-3 -2 -1 0 1 2 3
5. I felt uncertain/nervous at the time of execution of the movement.		-3 -2 -1 0 1 2 3
6. Which joint(s) do you concentrate on during the course of motion?		
	Shoulder	-3 -2 -1 0 1 2 3
	Hip	-3 -2 -1 0 1 2 3
	Knee	-3 -2 -1 0 1 2 3
	Ankle	-3 -2 -1 0 1 2 3
7. I had the impression that I control the movement rather well.		-3 -2 -1 0 1 2 3

Figure 4. Questionnaire of subjective evaluation, part one.

Motor Learning Questionnaire
(Trampoline skill - vertical take-off and landing on the back)
Part II

(1: kinematics (kin.) info only, 2: kin. + muscle control info (dyn.), 3: No difference)

Name:

Method Comparison:

1. Which method could have been more helpful for your mental translation of the skill?	1	2	3
2. Which method will you suggest to others for teaching the skill?	1	2	3

Figure 5. Questionnaire of subjective evaluation, part two.

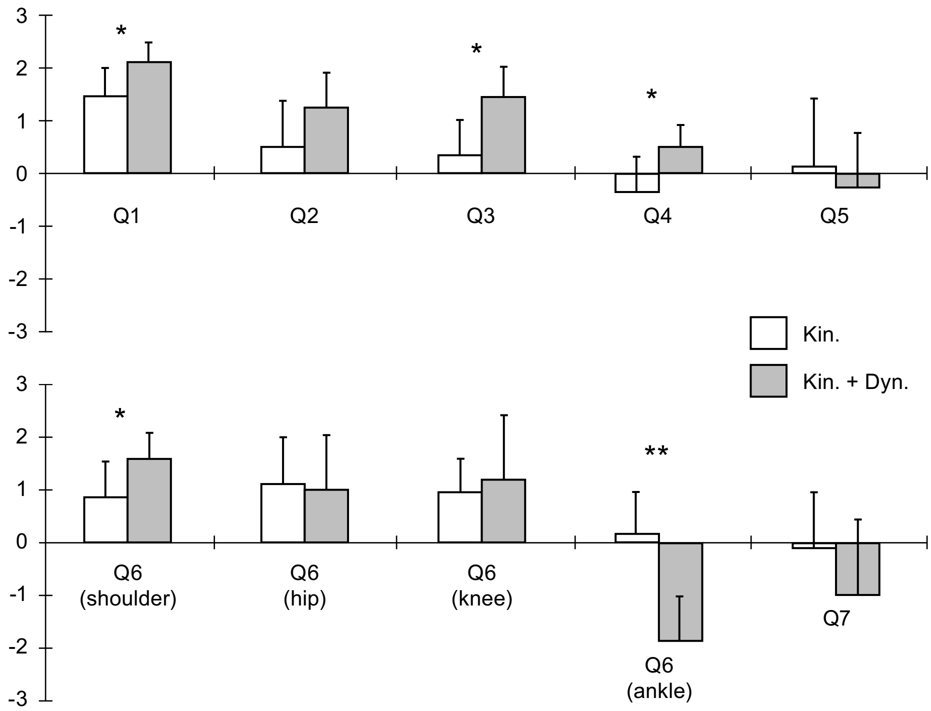

Figure 6. Knowledge of the skill - subjective judgments.
**: significant difference (p<0.05); **: high significant difference (p<0.01)*

control information, subjects from group two paid significantly higher attention ($p<0.05$) to the control of shoulders and neglected ankle control ($p<0.01$). Other perspectives lacked such significant differences ($p>0.05$).

The second part of the questionnaire was concerned with the subjective comparison of the two representations, whereby one method was not practised, but only mentally constructed. It was to decide, which source of information assisted (or would have helped) the students during the movement conception more. The results were in favor of method two, as regards the first question, half of the students were in favor of method two (Figure 7); however, there were 25% who perceived no differences between the two methods. The situation changed dramatically in the second question. 80% of the neutral group migrated to favor the second method. This change indicates that some students did not fully accept method two during trials; nevertheless, they considered that method two possessed more potential in improving the motor learning efficiency.

As for the objective analyses, it was shown that the second method resulted in a better performance. Specialists granted higher ratings to the performance of the muscle control group

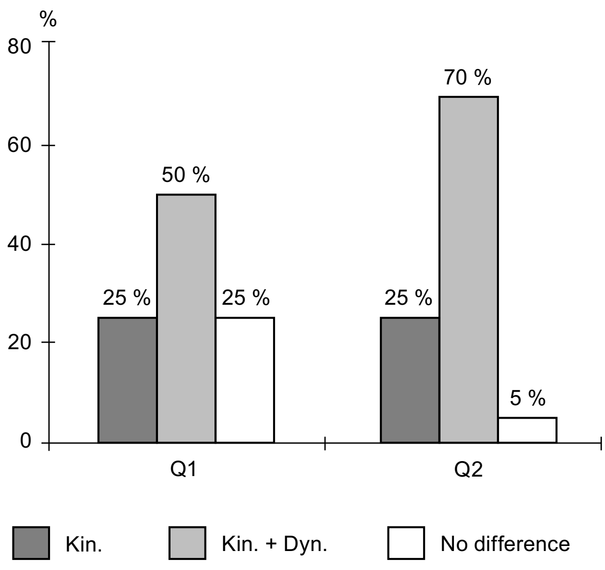

Figure 7. Subjective comparison of the learning methods.

than the conventional method group (Figure 8). Although the superiority is not significant ($p=0.16$), a stronger approximation to the target exercise was achieved. The significant level of 16% denotes an improvement in learning for over 80% of the cases, which confirms the supremacy of method two.

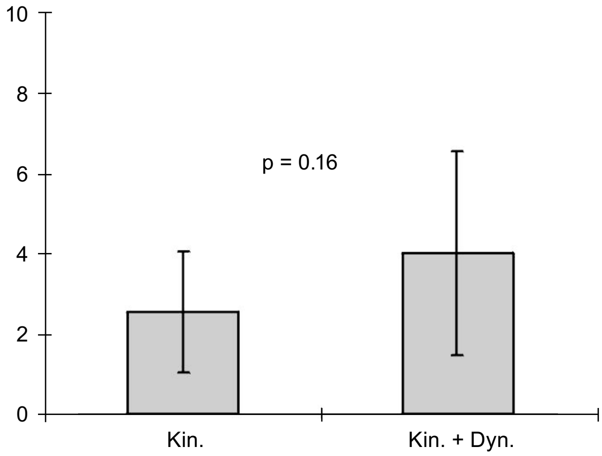

Figure 8. Performance comparison - Objective Assessment from Experts (Video analysis).

Discussion and conclusions

One of the problems for motion analysists in practice is how to communicate with practitioners, especially in the discussion of airborne movements. The description based on kinematic characteristics is often contradictory to the practitioners' experience. In fact, such a description could not interpret the movement control of practitioners because of the incompatibility of the systems (inertial and non-inertial) and the physics chain effect (Shan et al., 2004). In order to overcome the problem, a common communication base is vital. One potential solution may be in the muscular moments derived from individual anthropometric data and kinematic characteristics with the help of inverse dynamic analysis. The purpose of this study was to verify that the muscular moments obtained through inverse dynamics could improve the communication and simplify the motor learning process. The verification was done both subjectively and objectively.

From the subjects' input, the following points were revealed:

- Question 1 unveiled that utilizing the muscular moments as control signals positively influenced the creation of a conception of a new movement, namely the procedural knowledge (how to do, Magill, 2001). In comparison to method one, a significant improvement was seen.
- Concerning the movement control, it was revealed that the subjects who learned through method two gained more knowledge than those who learned through method one. Although the difference was not significant ($p>0.05$), it signified a tendentiously higher self-assurance in method two regarding the success of completing the movement.
- Question 3 clarified that an intensification of the movement conception was seen through practice in both groups. However, a significantly higher intensification ($p<0.05$) was found again in group two. The result portrayed a more swift knowledge-gaining process utilizing method two as opposed to method one, because the procedural knowledge is almost identical with the task-intrinsic feedback (the control feeling, Magill, 2001). Therefore, method one, which was mainly dependent on the subjects' previous motor control experience in a learning process, was less effective.
- Likewise, the estimated agreement of one's movement with the information supplied in group two was significantly more enhanced than that of group one. Therefore, the knowledge of muscle control was able to provide subjects in group two with an improved estimation of to what extent their movements correspond with the visual representation. The negative rating scale of group one unveiled that the subjects did not know, on average, how their movement precipitated.
- The answer to question 5 demonstrated the presence of a tendentiously safer feeling (not significant, $p>0.05$) in the traditional information method group.
- According to the subjective evaluation of the attempts, there were two significant discrepancies ($p<0.05$) in the movement control (Q6 - shoulder and ankle, Fig. 6). The attempts of group two neglected to control the foot movements since method two did not supply information for this. Because of the small influence of the foot movements on the total passage, the information regarding foot joint control was consciously omitted so as to direct the concentration of the learning onto other joint controls substantially. The desired additional attention of the movement control was observed on shoulder-control in group two. Unfortunately, this desired attention could not be acknowledged for the hip and knee joint movements by the subjects. This revealed that both groups set their attention of movement control on hip and knee.
- The last point in the questionnaire, however, exposed one advantage for method one, even though it was not significant ($p=0.11$). The grade of satisfaction with the learning effect

was higher in group one than in group two. It is no wonder that the more one knows, the more divergence will be identified, and the stronger the dissatisfaction.

The positive influence of method two on the learning of the movement can be further acknowledged with the analysis of Questionnaire part II. In question one, 50% of the subjects consented to the ascendancy of method two. Only 25% of the subjects supported the opinion of the traditional representation already being sufficient for the formation of the movement conception. The rest of the subjects (25%) did not observe a difference between the two methods. An interesting development was seen in the response to question two. 70% of the subjects favored method two, 25% remained in favor of method one and only 5% stated that both methods were equal. According to the neutral subjects, the cause was the abundance of information given in method two. It was difficult to understand the connection between the movement and the information supplied in a short period (during the experiment). Nevertheless, most subjects reflected an elevated reasonability in method two for the understanding of their movement control. If one completly understood the information supplied, the preference/advantage would be given to method two.

The supremacy of method II was further confirmed by objective evaluation. The objective analyses expressed a higher percentage of subjects in group one (5 or 50%) than in group two (2 or 20%) who showed no hip joint overstretching in the initial phase, which was a critical phase. Without the required hip over--extension at the beginning, the subjects could only achieve the landing position by producing angular momentum during the jump. Thus, the subjects who did not execute this hip over-extension would also not fulfill the precondition for the execution of the skill. Likewise, the initial knee flexion was achieved by fewer subjects in group one. Instead, the simultaneous flexion of hip and knee, a non-standard development in the sense of an approximation to the target exercise was detected. These included the active knee rotation in passive phase, which was also a critical phase during the learning of the skill.

The significance level of objective evaluation is only 0.16, which challenges the validity of the method. This raises a fundamental inquiry – how could we evaluate a training method in kinesiology? Mathematically, the significant level is chosen arbitrarily. A consideration on the nature of a problem is a crucial factor for the decision. There are circumstances where a significant level of 0.1 might be appropriate (Hardyck & Peterinovich, 1969). The above suggests that kinesiologists should consider the problems of the nature of movement science for any interpretation using a defined significant level, i.e. we need to distinguish the domains dealing with basic human motor skills with high responsibilities or risks (e.g. medicine) from *those without them* (e.g. sports). Unfortunately, the statistical significant levels commonly chosen in medical and biological sciences ($p<0.01$ and $p<0.05$) are widely applied in scientific publications. Such strict criteria are used to prevent treatment-induced errors, e.g. if we set our limits at 0.01, we expect to make one error in every 100 inferences. Unlike medical practitioners, kinesiologists usually explore advanced human motor skills as well as their potentials. Such skills are often mastered by only a few people among us and *are not the basic skills that maintain life and/ or daily activities.* Every experienced coach or practitioner knows that the bias existing among individual physical conditions achieves a success rate far below 95% for any complex motor skill acquisition, even by applying the same means and learning environments. Therefore, if we set our level of confidence so strictly, we run the risk of overlooking many of the real differences that exist among different training methods (Type II error of using statistics). Judging from the practitioner's point of view, a method, which would be considered to be very productive bringing 70% of students to a successful level.

Regarding the comparison of the subjective estimations as well as the objective evaluations, it can be summarized that the information of muscular moments does ease the communication amongst the three parties and simplify motor skill learning.

A biomechanical analysis of joint muscular moments in an airborne movement is well suited for improving communication with athletes and coaches as well as for improving efficiency of learning by supplying control information.

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KAKO DINAMIČKO MODELIRANJE TIJELA KRUTIM SEGMENTIMA MOŽE BITI KORISNO U MOTORIČKOM UČENJU? - UČENJE IZVEDBE UZ POMOĆ DINAMIČKOG MODELIRANJA

Sažetak

Uvod

Svrha ovog istraživačkog projekta bila je premostiti jaz između znanstvenika koji se bave istraživanjima pokreta te sportaša i trenera uspostavljanjem platforme za komunikaciju između triju skupina. U prvom dijelu projekta (Shan i sur., 2004) utvrđeno je da: 1) su razlike između vanjske perspektive (analitičari pokreta), unutarnjeg pogleda (dojam sportaša) i unutarnjeg gledišta iz vanjske perspektive (treneri) uzrokovane inercijalnim (nepomičan u odnosu na okolini) i neinercijalnim (nepomičan u odnosu na sportaševo tijelo) sustavom, kao i uparivanjem segmenata tijela; 2) rotacije zglobova nisu jednake mišićnim momentima, stoga se mogu pojaviti pasivne rotacije; 3) kritične faze u kontroli vještine, koje se mogu otkriti korištenjem simulacije modela, iznimno su važne za učenje i da ih se treba u tom procesu naglašavati i 4) dinamičko modeliranje može poslužiti kao platforma za povezivanje i ujednačivanje tri različita pogleda te pridonijeti stvaranju cjelovitije slike o ljudskoj motoričkoj kontroli. Stoga, radi uspostavljanja što bolje komunikacije sa sportašima i trenerima, analitičari pokreta ne bi trebali stati na deskriptivnoj razini, koja nudi jedino kinematičke parametre vještine. Takva deskripcija dokazano odstupa od sportaševa osjećaja kontrole ili trenerova iskustva.

Iskusni su treneri svjesni da je za pojednostavljivanje motoričkog učenja ključno učeniku / sportašu prenijeti znanje o tome koji su specifični mišići uključeni u pokret, kolika je sila potrebna te kakvo je stvarno vremensko-prostorno usklađivanje (timing) nužno za motoričku kontrolu. Ti aspekti pokreta pripadaju kontrolnim parametrima i mogu se izvesti iz dinamičkog i inverznog dinamičkog modeliranja. Takav scenarij sugerira da se dinamičko modeliranje može koristiti kao platforma za unapređenje komunikacije između analitičara pokreta i onih koji to realiziraju u praksi. U drugom dijelu projekta (predstavljenom u ovom broju) konstruiran je model za učenje koji je utemeljen na razmatranjima iz prvog rada. Bit je modela opskrbiti onoga koji uči upravljačkim informacijam - mišićnim momentima. Takve se informacije mogu pojedinačno priskrbiti primjenom inverzne dinamičke analize na konstruiranom modelu tako da individualne antropometrijske karakteristike i kinematički parametri koje treba naučiti budu ulaz za modelnu analizu. Na taj se način dizajnira individualiziran program učenja koji sadrži: 1) dobivanje kinematičkih karakteristika vještine koju treba naučiti korištenjem zahvaćanja pokreta (motion capture) i analize, 2) zamjenjivanje modelnih antropometrijskih podataka podacima osobe koja uči i primjenu inverzne dinamičke analize na model kako bi se utvrdili zglobno-mišićni momenti, što onome koji uči daje individualizirane važne kontrolne informacije i 3) primjenu kontrolne informacije u procesu učenja vještine.

Rezultati i rasprava

Model je procijenjen u istraživanju iz područja motoričkog učenja. Uzorak ispitanika činilo je 20 studenata sporta, podijeljenih u dvije grupe. U okviru eksperimenta istraživala su se dva aspekta učenja – znanje o pokretu i izvedba pokreta. Prva je grupa učila vještinu na konvencionalan način, koristeći se samo vizualnim informacijama. Druga je grupa uz vizualne informacije dobila i dodatne informacije o kontroli mišića. Istraživanje je evaluirano fenomenološki (pomoću upitnika) i objektivno (ekspertnom analizom video zapisa). Rezultati su pokazali da je prema, mišljenju ispitanika, metoda koja je uz vizualne nudila i kinematičke informacije kao i informacije o kontroli mišića bolja i da omogućuje bolje razumijevanje vještine. U okviru objektivne analize eksperti su procijenili da je izvedba grupe koja je imala dodatne informacije bolja od izvedbe ispitanika koji su učili na uobičajen način.

Zaključak

S obzirom na usporedbu subjektivne i objektivne procjene, može se zaključiti da se informacije o mišićnim momentima, dobivene na osnovi inverznog dinamičkog modeliranja, mogu koristiti kao kontrolni obrazac te da olakšavaju komunikaciju između tri skupine sudionika motoričkog učenja i da proces učenja pojednostavljuju.