METHODOLOGICAL ARTICLE

ISSN 1413-3555
Rev Bras Fisioter, São Carlos, v. 12, n. 5, p. 425-31, Sept./Oct. 2008
Revista Brasileira de Fisioterapia©

Two different methods for kinematic analysis of head movements relating to eye-head coordination in infants

Dois métodos diferentes para análise cinemática dos movimentos de cabeça durante a coordenação viso-cefálica de lactentes

Lima CD[1], Carvalho RP[2], Barros RML[3], Tudella E[1]

Abstract

Background: Kinematic analysis is a method for quantitative assessment applied in different fields of study. In the field of motor development, this analysis may promote better understanding of the acquisition and development of motor skills. **Objective:** To develop and compare two experimental set-ups for kinematic analysis of head movements relating to eye-head coordination (EHC) in infants. **Methods:** Two experimental set-ups (A and B) were tested. They differed from each other regarding the numbers and locations of the cameras, and regarding the volume of the calibration system. **Results:** The accuracy of the two experimental set-ups was 2.47mm, thus indicating that both can provide realistic reconstructions of the movement. The three cameras used in set-up B made it possible to view the full range of motion with at least one of the cameras. This led to improvement of the qualitative analysis and reduction of the time taken to process quantitative data, which was 33% shorter than seen with set-up A. In addition, set-up B presented a better cost-benefit relationship. **Conclusions:** Although both set-ups were adequate for kinematic analysis of head movements relating to EHC in infants, set-up B is more advantageous. The methodology for set-up B can be used in studies investigating head movements in either typical or atypical infants. The results from such studies could be used to complement assessments on at-risk infants and consequently could assist in implementing early interventions.

Key words: kinematic; eye-head coordination; head movement; methodology.

Resumo

Contextualização: A análise cinemática é um método de avaliação quantitativa empregada em diferentes áreas de estudo. Na área do desenvolvimento motor, essa análise pode proporcionar uma melhor compreensão da aquisição e do desenvolvimento das habilidades motoras. **Objetivos**: Desenvolver e comparar dois arranjos experimentais para análise cinemática dos movimentos de cabeça durante a coordenação viso-cefálica (CVC) em lactentes. **Materiais e métodos:** Foram testados dois arranjos experimentais (A e B) que diferiam quanto ao número e posicionamento das câmeras, bem como quanto ao volume do sistema de calibração. **Resultados:** A acurácia dos dois arranjos experimentais foi de 2,47mm, indicando que ambos podem fornecer uma reconstrução verossímil do movimento. As três câmeras usadas no arranjo B favoreceram a visualização de toda a amplitude do movimento por pelo menos uma das câmeras. Isso levou à melhora da análise qualitativa e à redução do tempo de processamento dos dados quantitativos, reduzindo-o em 33% quando comparado ao arranjo A. Além disso, o arranjo B apresentou melhor relação custo-benefício. **Conclusões:** Ambos os arranjos são adequados para a análise cinemática dos movimentos de cabeça durante a CVC de lactentes, entretanto, o arranjo B é mais vantajoso. A metodologia do arranjo B pode ser empregada em estudos que investigam o movimento de cabeça de lactentes, sejam eles típicos ou atípicos. Os resultados de tais estudos poderão ser empregados para complementar a avaliação de lactentes de risco e, conseqüentemente, auxiliar na intervenção precoce destes.

Palavras-chave: cinemática; coordenação viso-cefálica; movimentos de cabeça; metodologia.

Received: 21/02/2008 – **Revised:** 29/04/2008 – **Accepted:** 12/06/2008

---

[1] Physical Therapy Department, Neuropediatrics Section, Neuropedriatics and Motricity Studies Center, Universidade Federal de São Carlos (UFSCar) – São Carlos (SP), Brazil

[2] Health Sciences Department, Universidade Federal de São Paulo (Unifesp) – Santos (SP), Brazil

[3] Physical Education School, Biomechanics Instrumentation Laboratory, Universidade Estadual de Campinas (Unicamp) – Campinas (SP), Brazil

Correspondence to: Carolina Daniel de Lima, Américo Brasiliense Avenue, 473, Vila Rezende, CEP 13405-244, Piracicaba (SP), Brazil, e-mail: caroldaniellima@yahoo.com.br

Introduction

Kinematic analyses of human motion have been used as a method of quantitative evaluation, which by means of the interpretation of results allows inferences about movement detail. Such analyses have been widely applied in different areas of study of human movement, either for assessing the development of athletes during sports practice[1] and the effects of rehabilitation[2-4] or to improve the knowledge about development and development and motor control in infants and adults[5-9]. Especially in the motor development area, researchers use kinematic analyses as a tool for understanding motor skill acquisition and development in infants, such as reaching and kicking skills[10-15].

Head movement is among the motor skills that are important for global motor development in infants[16]. Babies are able to actively move their heads since birth, whether for feeding, when they search for the mother's breast, or to liberate the airways, when placed in a prone position. By the end of their first semester, infants show active head movement control, as the primary sensory-motor coordination is already developed, head and trunk posture control are enhanced, and some anti-gravitational postures have been acquired.

Eye-head coordination (EHC) consists in fixing the gaze on an object and following it simultaneously with eye and head movements. This coordination is present naturally during the first days of the infant's life and develops acutely during the first four months, contributing considerably to head and anti-gravitational postural control[16,17].

As EHC develops in the infant, visual activities are performed with greater range and efficiency, with increased contribution of head movement, increased synchronization between object displacement and visual tracking and a decrease in eye movement[18,19]. Furthermore, EHC development allows infants to perform the adjustments required for manual reaching development[20], and hand exploration.

Given the importance of head movement during EHC for global motor development in infants, and the lack of protocols for its measurement, it is necessary to develop a methodology that allows accurate quantification while investigating these movements. This is even more important during the period of the acquisition of head control (newborn to four-months old) because the current literature is limited to studies that performed kinematic analyses (using one or two cameras) only of the head rotation, associated with eye electro-oculography. The present study aimed to develop and compare two experimental conditions for kinematics analyses of head movement during EHC in infants.

Materials and methods

Subjects

This study was carried out with a sample of three healthy infants, born at term (38±1 weeks of gestational age), with a mean birth-weight of 3,326.67g (±336.50). After the approval (nº.289/2006) by the Ethics Committee of the Universidade Federal de São Carlos and parental consent through signature of the informed consent form were obtained, the infants were evaluated monthly from birth to four months of age, close to their birth date (± seven days). This age range was chosen because it is the period during which both head control and EHC develop in healthy infants.

Procedures

Calibration system and equipment disposition in laboratory

In order to describe a point's movement, it is necessary to know its position in space in relation to a given reference and as a function of time[21]. This reference, called calibration system, is determined by known X, Y, and Z coordinate points, which will be input into the analysis system. In the present study, this system consisted of six plumb lines measuring 2.3m. Twenty-five retro-reflexive markers, each 0.5cm in diameter, were placed 5cm apart throughout the lines[22]. The X, Y, Z coordinates of the markers were measured by means of a digital Total Station (Leica). X and Y axes were plane coordinates, related to the "0" point (0,0), while the Z axis was the height differences between the markers and the system's "0" point. The calibration system volume contained all movements of the object to be tracked, thus assuring precise measurements.

Two experimental conditions (A and B) were tested to establish the number of cameras (JVC/GY DV-300), their disposition in the laboratory (4.5 x 5.0m) and the most adequate calibration system volume for head movement analyses during EHC. In condition A, usually adopted in research involving spontaneous kicking and reaching[13-16,22], four digital cameras (C1, C2, C3 and C4) on 1.45m-high tripods were distributed, in pairs, lateral-diagonally to the infants' evaluation chair (Figure 1A). In this experiment, camera locations (X, Y and Z coordinates) were: C1 (0.06m, 1.76m, 1.43m), C2 (0.48m, 2.92m, 1.45m), C3 (3.76m, 3.02m, 1.46m) and C4 (3.72m, 1.58m, 1.43m), and the calibration systems had a volume of 0.64 x 0.84 x 0.35cm^3. For condition B, three digital cameras (C1, C2 and C3) were placed on tripods and distributed as follows: one posterior and superior to the infants' evaluation chair, at a height of

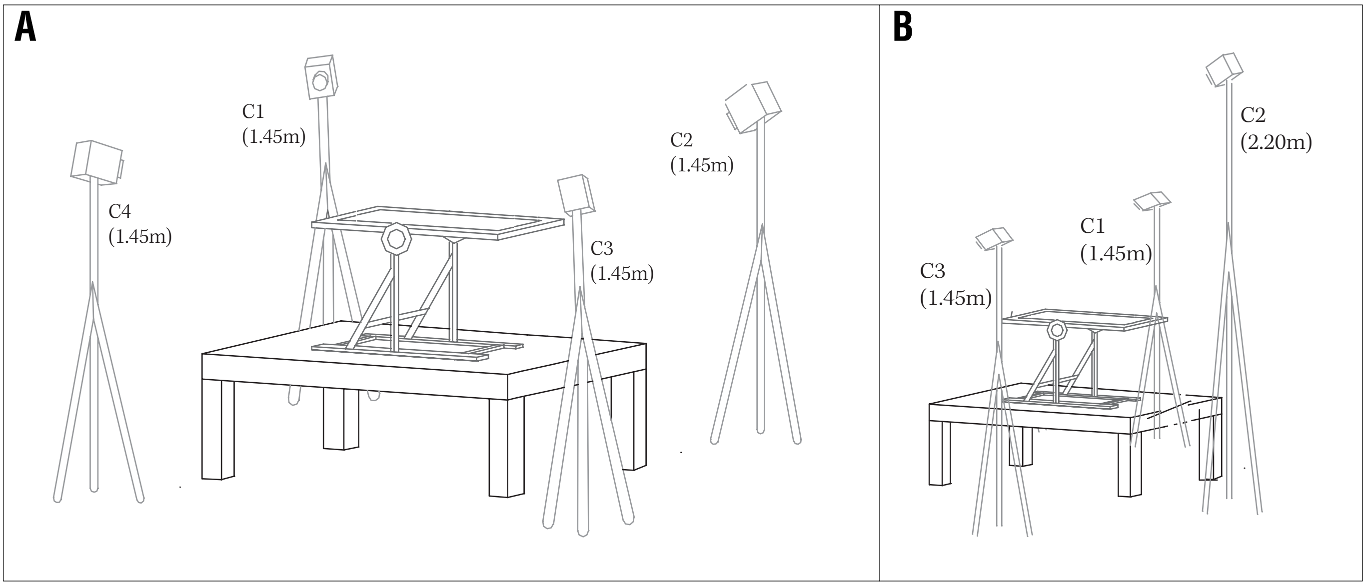

Figure 1. Camera, table, and assessment chair positions in experimental conditions A (Figure 1A – adapted from Landgraf[22]) and B (Figure 1B).

2.20m; and two laterally to the infants' chair, at a height of 1.45m. Camera locations were: C1 (0.84m, 0.24m, 1.10m), C2 (1.45m, 2.39m, 2.13m) and C3 (2.22m, 2.28m, 1.16m) (Figure 1B), and the calibration system had a volume of 0.64 x 0.36 x $0.35cm^3$. The decrease in volume of the calibration system was implemented for condition B in order to restrict camera framing of the infants' head, contributing to close-up shots, and consequently, to the qualitative analysis of the movement. During image acquisition, lights were placed laterally to the chair, illuminating the markers indirectly so as not to interfere in the infants' behavior. The cameras were set and adjusted to manual mode, manual zoom, shutter opening time, focus and white balance parameters before the beginning of data collection. From this moment on, no changes were made to camera parameters, which remained turned on until the end of the assessment, thus avoiding changes in the data sampling parameters.

The calibration system was recorded for approximately ten seconds, at a 60Hz frequency. After this period, the wires were removed, the infant was placed in position, and the evaluation took place.

Experimental protocol

The markers were objects attached to pre-determined points of the body to help track the movements of these points. In the present study, three passive, retro-reflexive markers, measuring 0.5cm in diameter[23,24], were attached to the infants' anatomical head points as follows: right (M_1) and left (M_3) zygomatic arches; and parietal bone vertex (M_2)[25,26] (Figure 2). The marker positions were defined by considering the infants' head as a rigid object. However, all objects are deformed to a greater or lesser extent, and to assume that an object is rigid facilitates movement analyses[25-27].

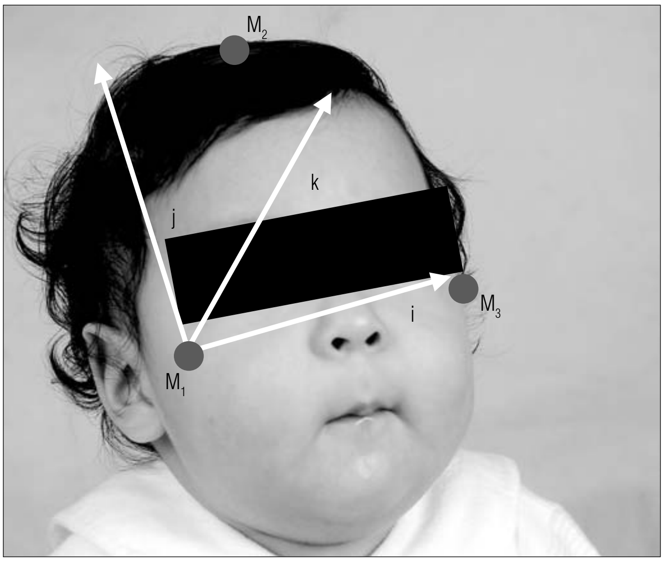
[redacted]

Figure 2. Positions of the markers (M_1, M_2, and M_3) (adapted from Andrade[25]), and vectors i, j and k for M_1.

With the markers in place, the infants were placed in a supine position on the evaluation chair (0° with the horizontal line). After acclimatization for 20 seconds, a visual stimulation card containing a black and white drawing of a face was placed 25 to 30cm from the infants' face at eye level. Fixation of the infants' gaze on the card was verified by means of the card's image being reflected on the infants' pupil, a method used for verification of visual preference[28]. After the infants' gaze was fixed on the card, it was slowly moved in the transversal plane with the purpose of stimulating EHC and, consequently, head movement. It is noteworthy that in both experimental conditions, the stimulation card did not prevent marker visualization by the cameras during head movement. Total card presentation time was two minutes and a flash was used, before the beginning of the evaluation, to synchronize the cameras. Its shot time was equivalent to a film frame.

Movement reconstruction using Dvideow®

Although there are several motion analysis systems available on the market, this study opted for Dvideow® 5.0[29,30] because it is a Brazilian system, and has been used in other studies[13-16]. During the evaluation, images were recorded on digital videotapes and, later, transferred to .AVI format files, as required by the system. An image caption card and Studio 9® software program were used for that purpose. In the Dvideow® system, files were loaded and synchronized from the identification of the frame that revealed the flash shot when the experiment began. After synchronization, the images of the frames at the beginning and end of each movement were identified. The beginning of the movement was defined as the moment in which the infant initiated head movement towards the object, after fixing their gaze on the stimulation card. The end of the movement was defined as the moment in which the infant moved their gaze away from the stimulation card.

For tridimensional movement reconstruction, it is necessary that the marker be visualized by, at least, two cameras. In this sense, it became necessary to divide the tracking into two parts: from the right side until the center line, and from that point towards the left side. In experimental condition A, movements initiated on the right side and were tracked by C1 and C2 cameras, while the ones initiated on the left, were tracked by C3 and C4 cameras. In condition B, the movements initiated on the right side and were tracked by C1 and C2 cameras, while the ones initiated on the left were tracked by C2 and C3 cameras. The next step towards movement reconstruction consisted of marker tracking. Dvideow® allows automatic recording of the filmed marker coordinates, known as tracking, and manual correction in the case of they are not recognized automatically during the trajectory. Tracking was obtained by integrating the resources of segmentation (recognizing marker features in the registered images), prediction (constraint of the search region of the markers thus reducing execution time) and the correspondence between the recognized markers in two consecutive frames.

The screen coordinates of the markers in the calibration system were also obtained. With these coordinates and the coordinates from the tracked movement as well as the calibration system parameters, the X, Y and Z coordinates of the markers placed on the infant's head were obtained by the direct linear transformation method.

Kinematic variable calculation

After tridimensional space reconstruction with the Dvideow® system, a file with X, Y, Z coordinates of marker locations during the EHC movements was obtained. Afterwards, data were filtered using Matlab® 6.1, with a fourth-order Butterworth filter and cutoff frequency of 6Hz. The head movement angle calculations variables during EHC (range of motion for flexion/extension, inclination and rotation and instantaneous angular velocity) were then calculated. As such, it was necessary to build an orthogonal basis with the origin in M1 (Figure 2). Flexion-extension angles were calculated by means of the movement around the i axis; the rotation angles, around the j axis, and the lateral inclination angles, around the k axis. The head flexion-extension, inclination and rotation ranges were obtained by using equation 1, while instantaneous velocity was obtained by means of equation 2:

Equation 1

$$flex(n,1) = \arccos\frac{\langle k(n,\cdot), z\rangle}{\|k(n,\cdot)\|\|z\|} * \frac{180}{\pi} \quad ;$$

$$incl(n,1) = \arccos\frac{\langle k(n,\cdot), y\rangle}{\|k(n,\cdot)\|\|y\|} * \frac{180}{\pi} \quad ;$$

$$rot(n,1) = \arccos\frac{\langle k(n,\cdot), y\rangle}{\|k(n,\cdot)\|\|y\|} * \frac{180}{\pi} \quad ;$$

in which flex, incl and rot correspond to the head flexion-extension, inclination and rotation ranges, respectively; n corresponds to the number of frames for each movement.

Equation 2

$$vel(i) = \sqrt{(dx * dx) + (dy * dy) + (dz * dz)}$$

in which i corresponds to the moment related to the movement; dx, dy and dz correspond to the instantaneous velocities in X, Y, and Z coordinates, respectively.

Angular variables (range of motion and instantaneous angular velocity) were selected because of the fact that the consulted literature does not report how the range and velocity of head movement during EHC develop during the first four months of age.

Accuracy of calculation

Compatibility between real movement and the three-dimensional reconstruction of the spatial coordinates of the markers, i.e. accuracy, could be tested by evaluating the variation in distance between the two markers attached to a long stick[25,26] inside the calibration volume. Thus, two markers were attached to a long stick (31 x 3 x 0.5cm) and randomly moved in the interior of the calibration volumes of experimental conditions A and B, at an interval of 300 frames. The actual distance between markers was 25.5cm. Accuracy (a) is calculated using the equation $a^2=(b^2+p^2)$, in which b is the measured bias, given by the differences between mean values obtained, and the real value, while p^2 is the variance of the values. The closer the result is to zero, the more precise the measurement is.

Results and discussion

The accuracy, the compatibility between real movement and three-dimensional reconstruction, and the time optimization of the analysis were compared between experimental conditions A and B.

Accuracy

In the present study, both calibration systems had different volumes. According to the accuracy results, a 2.47mm value was obtained for both experimental conditions. These values were within the patterns commonly used in the literature[22,23], and represented the measurement precision. In this sense, it can be inferred that both systems may be used in the three-dimensional reconstruction of head movement, as the obtained values were sensitive to small movement variations, such as the ones observed in head movement during EHC in the first months of age.

Compatibility between real movement and three-dimensional reconstructions

Camera positioning during experimental conditions A and B allowed the head movement reconstruction to be compatible with the real movement. However, experimental condition B (Figure 1B) provides the advantage of viewing the entire range of motion with one camera (C2), and generating a three-dimensional file with the X, Y, Z coordinates from all three markers. Furthermore, experimental condition B permitted a calibration system with less volume, which allowed greater camera close-up shots and consequently the observation of the infants' eye movement synchronized with the stimulation card. Therefore, this experimental condition contributed to both quantitative and qualitative analyses of head movement during EHC in newborn to four-month old infants.

Time of analyses optimization

An important aspect to be considered in quantitative kinematic analyses is that, for three-dimensional reconstruction to be carried out, it is necessary that each marker be visualized simultaneously by at least two cameras. In the present study, both experimental conditions respected this pre-requisite. However, experimental condition B appeared to be more advantageous than condition A in regard to optimization of the analysis time. Due to the smaller number of images and to the improved automatic tracking by increases in zoom, condition B took 33% less time to obtain the three-dimensional files than condition A. In terms of the cost-benefit ratio, condition B made the research faster and cheaper because it reduced the amount of equipment and materials needed.

An example of the application of the methodology for head movement analysis during EHC

In order to illustrate the methodology proposed for kinematic analyses of head movement during EHC, the longitudinal results of range of motion for flexion-extension (Figure 3A), lateral inclination (Figure 3B) and rotation (Figure 3C) of one of the three subjects will be presented.

Figure 3 A-C shows the range of motion obtained by the differences between the positions of the beginning and end of the curve. It also shows that small movement ranges (flexion-extension, inclination and rotation) were executed especially during the period from birth to two months of age. However, an increase in these ranges was observed as the infants became older. Thus, at four months of age, the infants demonstrated the greatest range of motion (approximately 53° of flexion-extension, 28° of lateral inclination and 40° of rotation).

The range gain of neonates was small; however, head movement during EHC was stable, that is, with subtle variations in range of motion. This is probably due to the neonates' neck length and physiological flexor pattern, which keep the shoulder girdle close to the head, stabilizing it in spite of the neck's hypotonia. Nevertheless, from the first to the third month, greater range of motion was observed. In contrast, instability (greater range of motion variations) was verified in head movement during EHC, possibly due to a decrease in the physiological flexor tonus, to an increase in neck length, and to the lack of synergy in the co-activation of the neck muscles. In the fourth month, the range gains were greater than in the previous months, and the movement curve was harmonious and without irregularities. It is hypothesized that this was due to the development of head control, resulting from the coordination between the agonist and antagonist neck muscles, to the decrease of the head in proportion to the trunk, and to the enhancement of visual acuity.

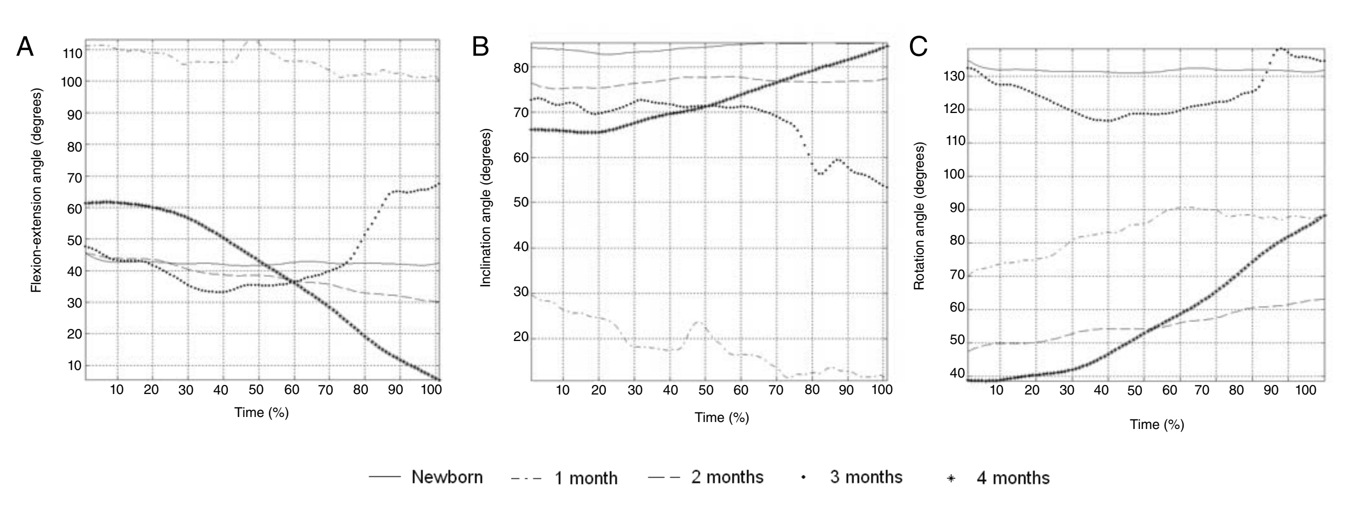

Figure 3. Curves for flexion-extension range of motion (Figure 3A), inclination (Figure 3B) and rotation (Figure 3C), normalized by the time of head movement during EHC of newborn to four-month old infants.

Conclusions

It can be concluded that both experimental conditions were adequate for kinematic analyses of head movement during EHC in infants from birth to four months of age. However, experimental condition B provided more advantages due to shorter time spent on processing the results, better cost-benefit ratio, and improved qualitative analyses. The methodology of condition B may be used in the study of coordination that involves head movement (e.g., audio-cephalic, audio-visual-cephalic), visual tracking, and head control, in both typical and atypical infants. Information provided by studies that use the suggested methodology may complement evaluations and early interventions performed on infants at risk.

References

1. Besier TF, Lloyd DG, Ackland TR, Cochrane JL. Antecipatory effects on knee joint loading during running and cutting maneuvers. Med Sci Sports Exerc. 2001;33(7):1176-81.
2. Lindquist ARR, Silva IAB, Barros RML, Mattioli R, Salvini TF. A influência da estimulação elétrica funcional associada ao treinamento em esteira com suporte parcial de peso na marcha de hemiparéticos. Rev Bras Fisioter. 2005;9(1):109-12.
3. Lindquist ARR, Prado CL, Barros RML, Mattioli R, Costa PHL, Salvini TF. Gait training combining partial body weight support, a treadmill, and functional electrical stimulation: effects on poststroke gait. Phys Ther. 2007;87(9):1144-54.
4. Pieruccini-Faria F, Menuchi MRTP, Vitorio R, Gobbi LTB, Stella F, Gobbi S. Parâmetros cinemáticos da marcha com obstáculos em idosos com doença de Parkinson, com e sem efeito da levodopa: um estudo piloto. Rev Bras Fisioter. 2006;10(2):233-9.
5. Silva JBF, Barros RML. Análise quantitativa e qualitativa dos sintomas de antecipação nas ações motoras de crianças. Rev Bras Cien Mov. 2000;8(2):19-24.
6. Barela JA, Godoi D, Freitas PB, Polastri PF. Visual information and body sway coupling in infants during sitting acquisition. Infant Behav Dev. 2000;23(3-4):285-97.
7. Barela JA, Jeka JJ, Clark JE. Postural control in children: coupling to dynamic somatosensory information. Exp Brain Res. 2003;150(4): 434-42.
8. Toledo DR, Rinaldi NM, Barela JA. Controle postural em crianças: efeito da manipulação da informação visual discreta. Revista Brasileira de Comportamento Motor. 2006;1(1):82-8.
9. Godoi D, Barela JA. Body sway and sensory motor coupling adaptation in children: effects of distance manipulation. Dev Psychobiol. 2008;50(1):77-87.
10. Thelen E, Spencer JP. Postural control during reaching in young infants: a dynamic system approach. Neurosci Biobehav Rev. 1998;22(4):507-14.
11. Fallang B, Saugstad OD, Hadders-Algra M. Goal directed reaching and postural control in supine position in healthy infants. Behav Brain Res. 2000;115(1):9-18.
12. Rocha NA, Silva FP, Tudella E. The impact of object size and rigidity on infant reaching. Infant Behav Dev. 2006;29(2):251-61.
13. Rocha NA, Silva FP, Tudella E. Influência do tamanho e da rigidez dos objetos nos ajustes proximais e distais do alcance de lactentes. Rev Bras Fisioter. 2006;10(3):263-9.

14. Carvalho RP, Tudella E, Savelsbergh GJ. Spatio-temporal parameters in infant's reaching movements are influenced by body orientation. Infant Behav Dev. 2007;30(1):26-35.

15. Carvalho RP, Tudella E, Caljouw SR, Savelsbergh GJ. Early control of reaching: effects of experience and body orientation. Infant Behav Dev. 2008;31(1):23-33.

16. Bly L. Motor skills acquisition in the first year. San Antonio, Texas: Therapy Skills Builders; 1994.

17. Erhardt RP. Developmental visual dysfunction. Model for assessment and management. Maplewood, MN: Therapy Skill Builders; 1993.

18. von Hofsten C, Rosander K. The development of gaze control and predictive tracking in young infants. Vision Res. 1996;36(1):81-96.

19. von Hofsten C, Rosander K. Development of smooth pursuit tracking in young infants. Vison Res. 1997;37(13):1799-810.

20. Bertenthal B, von Hofsten C. Eye, head and trunk control: the foundation for manual development. Neurosci Biobehav Rev. 1998;22(4):515-20.

21. Barros RML, Brenzikofer R, Leite NJ, Figueiroa PJ. Desenvolvimento e avaliação de um sistema para análise cinemática tridimensional de movimentos humanos. Rev Bras Eng Biomed. 1999;15(1-2):79-86.

22. Landgraf JF. Efeitos do acréscimo de peso nos chutes espontâneos de lactentes nos primeiros 2 meses de vida [dissertação de mestrado]. São Carlos: Universidade Federal de São Carlos, Centro de Ciências Biológicas e da Saúde; 2006.

23. Carvalho RP. A influência da postura corporal no movimento de alcance manual em lactentes de 4 meses de vida [dissertação de mestrado]. São Carlos: Universidade Federal de São Carlos, Centro de Ciências Biológicas e da Saúde; 2004.

24. Carvalho RP, Tudella E, Barros RML. Utilização do sistema Dvideow na análise cinemática do alcance manual de lactentes. Rev Bras Fisioter. 2005;9(1): 41-7.

25. Andrade LA. Análise da marcha: protocolo experimental a partir de variáveis cinemáticas e antropométricas [dissertação de mestrado]. Campinas: Universidade Estadual de Campinas, Faculdade de Educação Física; 2002.

26. Andrade LM, Araújo AGN, Barros RML. Análise de marcha: protocolo experimental para posicionamento e orientação dos segmentos do corpo humano baseado em sistemas de marcas técnicas. Revista Brasileira de Biomecânica. 2004;5(8):33-40.

27. Keller FJ, Gettys WE, Skove MJ. Física. São Paulo, SP: Makron Books; 1997.

28. Fantz RL. Patterns vision in newborn infants. Science. 1963;140(3564):296-7.

29. Figueiroa PJ, Leite NJ, Barros RM. A flexible software for tracking of markers used in human motion analysis. Comput Methods Programs Biomed. 2003;72(2):155-65.

30. Barros RM, Russomanno TG, Brenzikofer R, Figueroa PJ. A method to synchronise video cameras using the audio band. J Biomech. 2006;39(4):776-80.