THE ROLE OF STRENGTH IN THE DEVELOPMENT OF REACHING

Lia Out and G. J. P. Savelsbergh
Free University, Amsterdam

The aim of this study is to investigate whether muscle strength acts as a constraint during the development of reaching. An experiment is described in which reaching movements of infants at three, four and five months of age are registered (3D, 50 Hz) in three conditions: in supine, in sitting, and in sitting with weighted arms. Predictions concerning developmental changes in the kinematics and kinetics of the reaching movements are put forward.

Introduction

This contribution concerns the development of arm movements in young infants. A planned experiment is described in which we aim to go beyond the mere description of what an infant does in attempting to reach for and grasp an object suspended in front of him. Our ambition is to explain some of the processes involved in this aspect of motor development.

When an adult reaches out for an object the hand moves in an almost straight path towards the object, with highly reproducible patterns of muscle contraction. This apparently simple action requires a complex interplay: sense organs pick up information about the distance and location of the object; the nervous system receives this information and somehow provides the right muscles at the right time with the right stimulus; and, once activated, these muscles produce the required forces. In the young infant each of these subsystems develops at its own pace. It is not surprising then, that infant limb movements continuously change in appearance, because they arise from interactions between these heterochronously developing subsystems. As a consequence, simple observation of infantile movement does not suffice for a complete understanding of motor development. A case in point is the work of Thelen & Fisher (1982) who showed that appropriate experimental manipulations can challenge widely accepted conclusions drawn from observation. Thus, they demonstrated that the disappearance of the stepping reflex in infants at four weeks of age could be explained by the disproportionably large amount of body fat during this period, resulting in legs being too heavy to lift against gravity. This programme of research provided the inspiration for the main goal of the experiment to be described here: to determine the influence of muscle strength on infant reaching movements between three and five months of age.

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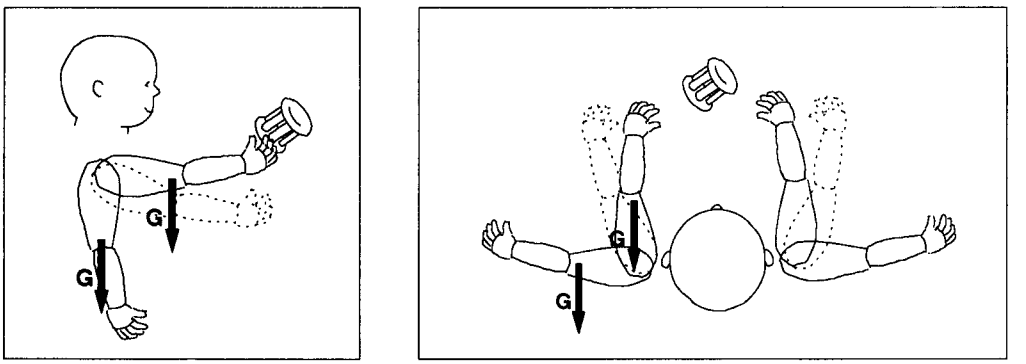
The idea that strength can be a constraint on infant reaching is suggested by observations in our own lab, showing that children between three and five months of age reach longer and with a greater frequency for brightly coloured balls when supported in a sitting position than in supine (Savelsbergh & Van der Kamp, submitted). These findings may be explained by the situation-specific nature of generating strength, in that there are contrasting force requirements in sitting and supine, arising from differences in the orientation of the infant realtive to the force of gravity. Lifting an arm in order to reach requires a certain minimal force: muscles around the shoulder joint must generate torques large enough to overcome the torque that gravity imposes on the arm (see Figure 1). The torque to be overcome becomes larger when mass increases and when the moment arm (the distance between the centre of mass of the arm and the shoulder) increases, for torque is the product of force and moment arm and force that of mass and acceleration. On the other hand, the torque that the muscles can generate depends on their maximum force, that is, on the amount of muscle material in parallel, and on the muscle's moment arm with respect to the joint. All of these parameters are subject to change during development, and whether an infant's force suffices to lift the arm depends on their relative contributions: the ratio between fat tissue and muscle tissue can, for instance, be so high that the mass of the arm is too large with respect to the cross sectional area of the muscles. In addition, the ratio between length and circumference of the segments can be so high that the moment arm of the gravitational torque is too long relative to the muscles' cross sectional area. Maresh (1961) measured tissue shadows on roentgenograms (n=50), and showed that, between two and six months of age, the amount of fat tissue in the extremities increases much more rapidly than muscle tissue.



(a) (b)

FIGURE 1 Gravitational torque in sitting (a) and supine (b). Gravitational torque equals G (arm mass x 9.81 m/s^2) x moment arm (shortest distance to shoulder joint).

The hypothesis we want to test, stemming from the observed difference in reaching behaviour between sitting and supine, and knowledge about the changing morphology of the arm, is as follows: *During development, the relationship between the continuously changing arm composition and geometry can become such, that muscle strength acts as a constraint on reaching and systematically affects the kinematics of arm movements.*

Method

To test this hypothesis, we currently carry out an experiment in which detailed analyses are made of the reaching movements of ten full-term infants in combination with anthropometrical measurements of their arms. Recordings are made at three, four and five months of age, because previous research showed that infant reaching is particularly sensitive to the orientation of the infant within the field of gravity during this period (Savelsbergh & Van der Kamp, submitted). The infants are comfortably secured in a chair whose orientation can be adjusted around a frontal axis. They are then confronted for a few minutes with a brightly coloured toy rattle which is suspended, just out of reach, in the body midline at shoulder height. Three conditions are used, in which the orientation as well as the magnitude of the gravitational force are manipulated: in one condition the infant is supine with the backrest of the chair at 0° to the horizontal plane, in the second condition the infant sits at an angle of 90°, in the third condition the chair is also angled at 90°, but now 60 g. weights are attached to about the middle of the forearms. White markers (∅ 1.8 cm) are fixed on the shoulders, elbows and wrists, thus providing a marked contrast with the dark background. Movements of each arm are registered by two video cameras (Super-VHS, 50 Hz). The camera coordinates of the markers are automatically detected by VIDIPLUS, a computer programme written in MODULA-2. Three dimensional coordinates are reconstructed using the Direct Linear Transformation method (e. g., Dapena *et al.*, 1982). The three dimensional coordinates will be used to determine trajectories, velocities and accelerations, of the wrist, angles of the shoulder and elbow joints, angular velocities and accelerations, and joint torques. The determination of three dimensional joint torques by means of inverse dynamics (e. g., Hardt & Mann, 1980) requires knowledge of segment masses, positions of the segment centre of mass and moments of inertia. Schneider and Zernicke (1992) provide regression lines for estimating of these quantities based on the following data: body mass, length and circumferences of the upper and lower arms. Furthermore, skinfolds of upper and lower arm are measured, and will, in combination with the length and circumference data, be used to estimate composition of the arms.

Predictions

What predictions ensue from our hypothesis that a lack of strength may constrain reaching during development? When an infant's fat ratio is relatively high, or when the ratio length-circumference of the arm is relatively high, we expect that the infant will avoid high muscular torques in attempting to reach for the object. High torques can be avoided in several ways: on possibility is to bend the arm which decreases the gravitional moment arm and thereby the torque to be overcome; another possibility is to swing the arm towards the object. A rapid onset of muscular torques in the initial phase of the arm movement gives rise to high angular accelerations and thus to high inertial forces, which then diminish the required muscular torques that have to be generated during the rest of the movement. A lack of strength can also result in the hand not coming within the vicinity of the object. It is likely then that the maximum of the muscular torques produced is similar across conditions, and represents

the limits of the infant's possibilities. In particular the conditions with the chair at 90° with and without weights attached to the arms are comparable, in that the gravitational torque only differs in magnitude and not in orientation. A comparison with the 0° condition is harder to make because in this orientation different muscles are involved in producing a reaching movement.

An alternative hypothesis for explaining differences in reaching between the three conditions is to attribute them to a lack of control of muscular forces instead of a lack of muscular strength. In order to successfully control muscular forces, external forces such as the gravitational force have to be taken into account. When this process does not yet function properly, it is very likely that in situations in which the external forces differ either in magnitude or orientation, the appearance of movements will differ. It is, however, not easy to predict the features of a movement which is not optimally controlled, because even in a system that is considered to be optimally controlled, namely the adult, the criterion of optimality and the parameters to be controlled are as yet unknown. An additional experiment is planned that will assist us in deciding whether the infants are constrained by a lack of strength or by a lack of control when their reaching movements differ between the gravitational conditions. A similar experiment as described above will be carried out with adults, whose muscular control can be assumed to be at a high level. A lack of muscular strength will be simulated by loading their arm segments (with the chair at 0° and 90°) in such a way that the distribution and relative magnitude of the mass of the arms are comparable to those of the infant. Deviations from unloaded trials, both kinematically and kinetically, will be used to generate additional predictions based on our original hypothesis that strength may constrain reaching during development.

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