

Hysteresis in perceptual-movement coordination

Abstract

The chapter discusses the observed changes in the coordination pattern of grasping which occur when picking up different size objects. It is shown that in the coordination between information and movement a discontinuous phase transition can be identified. Evidence is reported for robust body-scaling in the development of prehension. Furthermore, the presence of self-organising characteristics like sudden jump, hysteresis, enhanced variance and multistability demonstrates that the ratio between cube and hand size serves as a control parameter in the transition from one-handed to two-handed grasping.

Introduction

Movement coordination refers to the necessarily orderly relations among a very large number of moving part. This implies what Bernstein (1967) denoted as the 'degrees-of-freedom' problem: How are the *many* muscles (792) and joints (110) of the human body constrained to perform fluid coordinative actions? His definition of movement coordination is

'... the process of mastering redundant degrees of freedom of the moving organ, in order words, its conversion to a controllable system' (Bernstein, 1967; p. 127).

The question which now arises is: How are these degrees of freedom mastered? For any executive to effectively control each individual degree of freedom separately is an awesome and for all practical purposes an impossible task. Different theoretical paradigms approach this problem in different ways. For instance, Gibson's (1979) theory of ecological optics based on the notion of direct perception, posited a perception-action cycle whereby action resulted in perceptual information which tuned a group of muscles and joints into task-specific musculo-skeletal organisations. This functional organisation of a group of muscles and joints is called a coordinative structure (Turvey, 1990; Reed, 1982). These muscles and joints act like one system but do not necessarily need to be mechanical linked to each other (Tuller et al., 1982). They are a product of evolution, development, learning and steered by information. Thus, the degrees of freedom are mastered by the tuning of a whole group of muscles and joints to the information available in the environment. How this tuning takes place can be

understood by introducing the concept of constraint. It was Kugler and co-workers (Kugler et al., 1982), who proposed that (development of) movement coordination is brought about by changes in the constraints imposed upon action. Three categories of constraints are suggested by Newell (1986): organismic (e.g. nerve system), task (e.g. reaching with one hand) and environmental (e.g. information about object size). These different constraints do not operate in isolation, but together lead the functional organisation of muscle and joints. In this context, information can act as a constraint. These concepts are nicely illustrated by an experiment of Newell and co-workers (Newell, Scully, McDonald & Baillargeon, 1989a). In this study infants of 4 to 8 months old were presented with four object sizes (1.25, 2.50, 2.54 and 8.5 cm in diameter). It was found that the grasping behaviour could be classified primarily by 5 grips, while 1023 possible combinations of the 10 fingers could be used. The limited number of observed grasp configurations reflect the relation between different constraints, namely in this case hand size and object size and shape.

Another example how different constraints act is provided by the work of Thelen and colleagues spontaneous movements (Thelen, Fisher, & Ridley-Johnson, 1984). These researchers found that infants (2, 4 and 6 week old) in a supine position performed no steps. When they were held in an upright position, a temporal pattern similar to that of newborns engaged in kicking was found. In contrast, when the infants were held with their legs upright in water the newborn stepping pattern emerged, suggesting that organismic and environmental constraints interact.

For arm movements of 3 to 6 months old infants, a similar interaction of constraints was found. Savelsbergh and Van der Kamp (1994) seated infants in three positions: vertical, reclined and supine. They found that the reaching pattern of the 3 and 4 month old infants in the vertical position was similar to the reaching pattern of the 5 and 6 month old infants, while for the supine position the reaching pattern of the 3 and 4 month old infants was significantly different of the 5 and 6 month old infants. That is, lesser reaches for the 3-4 month old infants. Like the Thelen studies, Savelsbergh and Van der Kamp showed a significant influence of the changing interaction between environmental and organismic constraints. The authors explained their findings in terms of a gravity constraint (direction of the gravity force vector) and the age of the infant.

The goals of this chapter is, to show that changes in the prehensile coordination pattern occur as a result of changes between organismic and environmental constraint, that is the ratio between object size and hand size. Second, that in the changes in coordination can be understood as a discontinuous phase transition. In order to achieve these two goals, first, the concept of affordance and the relation between affordance and transitions is discussed. Followed by demonstrating the presence of self-organising characteristics like sudden jump, hysteresis, enhanced variance and multistability.

Affordances and transitions in perception-movement coordination

A central concept in the direct perception approach of Gibson (1979) is affordance. An affordance is:

'the functional utility of an object for an animal with certain action capabilities' (Warren, 1984, p. 683).

In these terms, the affordance an organism detects is related to its own action system, implying the use of a relative scaling and not an absolute metric for both perceiving and acting. For instance, the climbing of stairs is specified by the relation between the riser height and the leg length (Warren, 1984). Thus, the ratio between a metric of the environment and a metric of the climber's body. This relationship between these two metrics is expressed by the term body-scaled information. More in general, such ratios for controlling actions have been demonstrated for a variety of tasks like gait pattern (Alexander, 1984), sitting height (Mark, 1987), walking through apertures by adults (Warren & Whang, 1987) and by children (Savelsbergh et al., 1998), reaching in adults (Carello, Groszofsky, Reichel, Solomon & Turvey, 1989; Mark et al., 1997) and children (Barreiros & Silva, 1995; Newell et al., 1989a & b, 1993).

In these experiments transitions in coordination patterns are found. For instance, in the experiment of Newell, Scully, Tenenbaum and Hardiman (1989b), 3-5 year old children were required to pick up cubes differing in size and to place them into another slightly larger cube. It was found that despite the growth of hand size with age, shifts in grasping patterns were determined by a constant ratio between hand size and cube size indicating body-scaled information. Further, when the ratio between hand size and cube size was about 0.6, the children shifted from grasping the cube with one hand to both hands. Such ratio's, expressed in dimensionless pi-numbers, describe when a shift in behaviour occurs. However, they do not provide information about the nature of the shift. To examine the nature of the shift was precisely one of the goals of the Van der Kamp et al. study (Van der Kamp, Savelsbergh & Davis, 1998).

The nature of the shift

In the Van der Kamp et al. study (1989), thirty-three school children aged 5, 7 and 9 took part and were seated on a chair at a table. They were required to grasp a cube presented by the experimenter seated opposite to the subject. A set of 14 cardboard boxes with a size range from 2.2, 3.2, 4.2 etc. to 13.2, 14.2 and 16.2 cm in width were used. All boxes were easy to lift and weight differences were negligible with respect to the task requirements. The boxes were presented in, an increasing condition with sizes ordered from the smallest size to the largest, a decreasing condition, with the sizes ordered from the largest to the smallest, and twice in random order.

As expected a shift from one to two-handed grasping is found. In Figure 1, the mean percentage of occurrence of one-handed grasps for the three age groups is depicted. From the Figure 1a, it is clear that the older the children the higher the occurrence of one-handed grasps (37, 46, and 55% for the 5, 7 and 9 year old respectively). Moreover, the older the children, the larger the cubes that were taken with one hand.

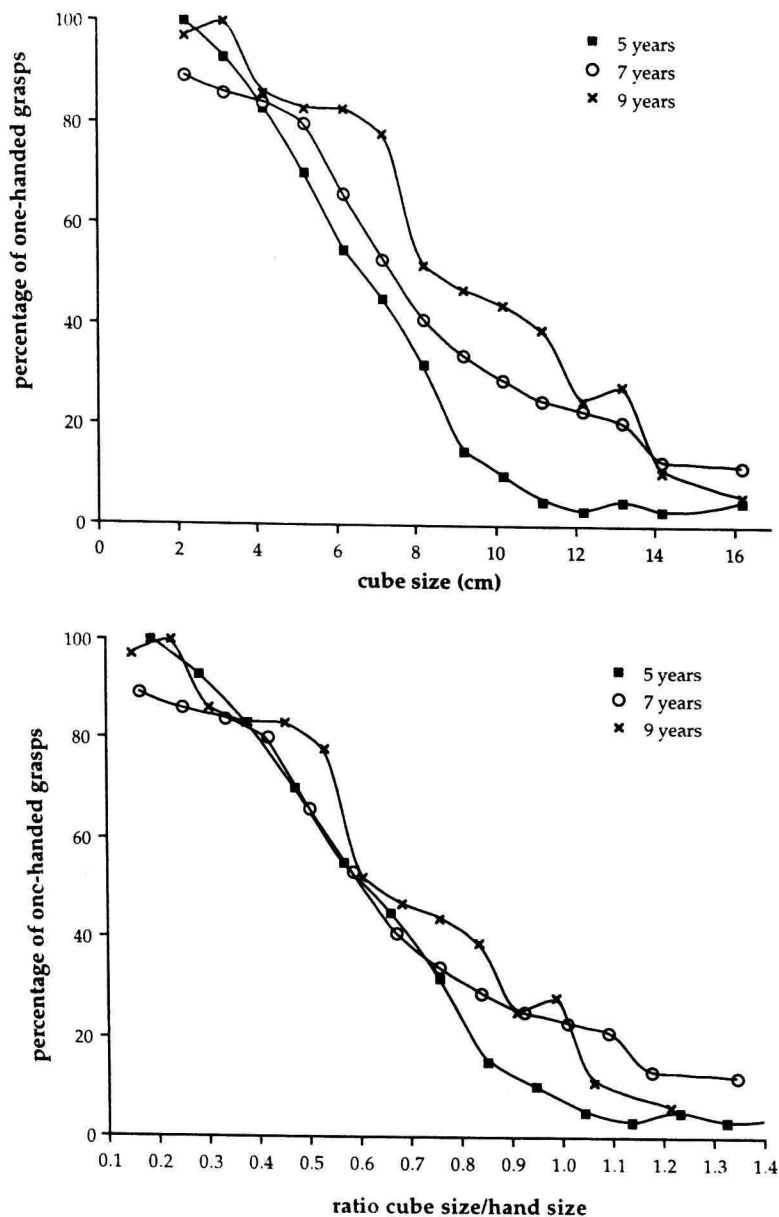


Fig.: 1. The percentage of one-handed grasping for the absolute (a) and relative measurement (b) as a function of age group.

Analyses on the percentage of occurrence of one-handed grasps revealed significant effects for Cube Size by Age. However, when the differences in grasping are expected to disappear when hand size is taken into account. To examine this the data

of Figure 1a are plotted differently, namely on a cube size/finger span ratio axis in Figure 1b. It can be seen that the curves for the different age groups overlap each other, which is suggestive for the use of body-scaled information (Warren, 1984; Newell et al., 1989a).

To formalise this finding, the mean cube size at which each child changed from uni-manual to bi-manual grasping was determined: the transition point. This was achieved by determining, first, for each separate trial, the size of the largest cube that was still grasped with one hand and for which also all smaller cubes were taken with one hand, and second, by determining the size of the smallest cube that was taken with two hands and for which also all larger cubes were taken with two hands. The transition point was defined as the sum of these two sizes divided by two. The resulting transition points were used to provide for each child the mean cube size for calculating the following ratios: Absolute Cube Size and Ratio Cube Size/Finger Span. The mean transition point for absolute cube size were 7.1 cm for 5, 8.2 cm for 7 and 9.7cm for 9 year old children, while the ratios were .68 for 5, .55 for 7 and .48 for 9 year old children.

The statistical analysis showed that the body-scaled ratio did not differ significantly between the age groups confirming the suggestion that when scaling to hand size, differences in grasping between the three age group disappeared.

Consistent with the prediction based on body-scaling, the Van der Kamp et al. experiment (1998) showed that for prehension a ratio between object and hand size defines the shift from one-handed to two-handed grasping, and that this ratio remains invariant during development. So far the study confirmed earlier findings. Now we will turn to the more specific nature of the shift.

Self-organisation in grasping

From a dynamical systems perspective (Kugler, Kelso, & Turvey, 1980; Kelso, 1995; Thelen & Smith, 1994), it is argued that movement patterns show signatures from self-organisation, rather than being specified by a priori prescriptive devices that 'tell the system what to do'. On a macroscopic level a movement pattern spontaneously emerges from non-linear interactions of various components at a more microscopic level of organisation. The order parameter refers to the macroscopic order of the system, which is stable (i.e., it does not change, and is relatively resistant to perturbations) for a range of values of a relevant but unspecific (i.e., it does not specify the movement pattern) control parameter. At critical values of the control parameter the system becomes unstable and a sudden shift to another movement pattern is observed. The continuous scaling of a control parameter causes a discontinuous change in macroscopic order, which is called a phase transition.

Indicative features for discontinuous phase transition

What are the indicative features for discontinuous phase transitions? In order to identify a discontinuous phase shift we need to find amongs other evidence for sudden jumps, hysteresis, enhanced variance and multistability. With a sudden jump is meant an abrupt change between movement patterns, such as the change from anti-phase to

an in-phase pattern like in Kelso's finger (1985) experiments. Hysteresis can be detected by scaling the control parameter up and down. A transition that does occur for a higher control parameter value when scaling up as it does when scaling down can be described as showing hysteresis. That is, when scaling up the cube size/finger span ratio, the shift from one-handed to two-handed grasping should occur at a larger ratio as compared to scaling down.

Also evidence for multistability and enhanced variance indicates that the shift is a discontinuous phase transition. The first is referring to the fact that more than one stable pattern can be observed. For instance, in the finger experiment both the anti-phase as well as the in-phase mode may occur for certain values of the control parameter. The second refers to an increased variability in relative phase before and during the actual transition.

The question now is whether we can find evidence for such a transition in our grasping data? Inspection of Figure 1b does not reveal an abrupt change or sudden jump. But, when data are normalized at the transition point an abrupt change can be observed.

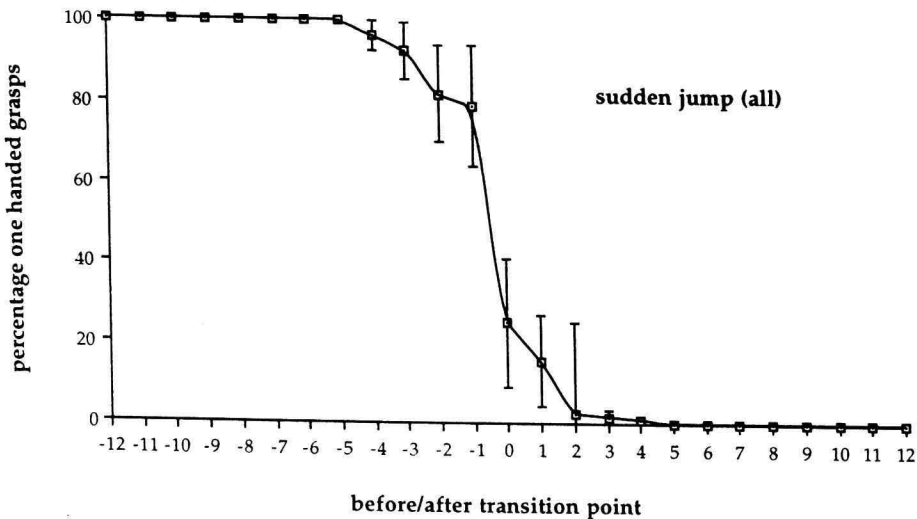


Fig. 2. The data normalized at the transition point.

In Figure 2 the effect of normalising is graphed. The data are further analysed by calculating the R^2 for the continuous and discontinuous models (Figure 3a & 3b). After scaling to the transition point, the discontinuous model fitted better to the data, albeit for the 5 years old the difference between both models is small. When comparing the models for the individual data scaled to transition point, the R^2 for the 7 and 9 years old were significantly higher for the discontinuous model, whereas for the 5 years old no significant difference between both models was found. In conclusion, a sudden jump is discerned for the 7 and 9 years old children.

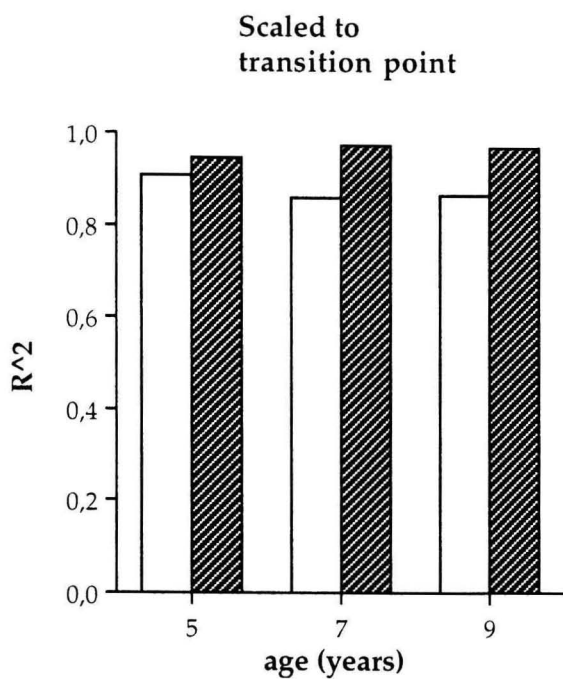
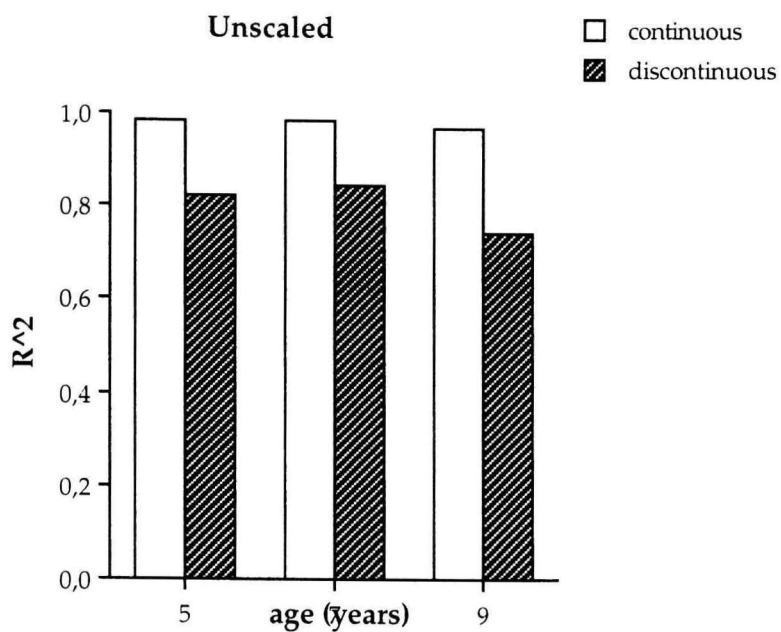


Fig. 3. The R^2 for unscaled and scaled data. See text for further explanation.

Hysteresis, enhanced variance and multistability in grasping

The presence of hysteresis is examined by comparing the two trials in which the cubes were sequentially presented (i.e., the increasing and decreasing condition). In Figure 4 is graphed for all three age groups when hysteresis occurred, the shift occurring at the same ratio in both sequences and the shift occurring at a lower cube ratio for the increasing sequence.

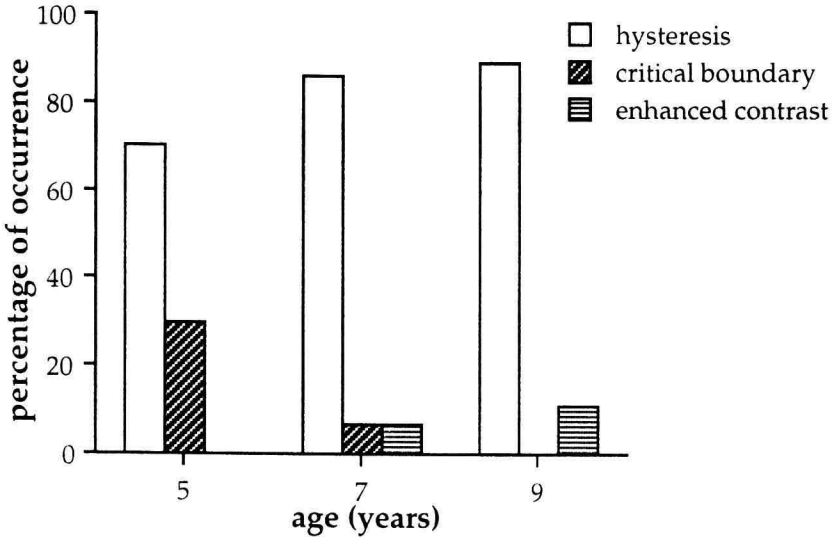


Fig. 4. The percentage of occurrence of hysteresis, critical boundary and enhanced contrast.

Clearly, in most (82%) subjects hysteresis was present. Only the 5 year old group showed a substantial amount (30%) of critical boundary cases. Analyses indicated that hysteresis was present in all three age groups.

When the averages of the intra-individual standard errors for each age group are scaled to the transition cube, a clear increase in mean standard error can be observed just before or at the cube at which the children changed from a one-handed to a two-handed grasping pattern (Figure 2a). This observed increase in variability is not simply due to the hysteresis effect because it concerns the variability after scaling to the transition point, but can be interpreted as reflection of increased variance.

In conclusion, the Van der Kamp et al. study (1998) demonstrates that the body-scaled ratio of object size and hand size may serve as a control parameter for switches in grasping action. Evidence for this contention is found in the combined presence of the sudden jump, increased variance just before and during the switch, multistability, and hysteresis. These features together indicate that the switch from one-handed to two-handed grasping is a discontinuous phase transition.

Concluding remarks

The goal of the chapter was twofold, that is, first to show that changes in the coordination pattern occur as a result of changes in the ratio between object size (environmental) and hand size (organismic) and, second, this change in grasping pattern is a discontinuous phase transition.

With respect to the first goal, it is found that grasping actions is guided by body-scaled ratio which is similar over individual differences in body dimensions. Developmentally, changes due to physical growth should not affect the perception of affordances. That is, during development children should remain tuned to similar body scaled ratios without the need for new learning or reorganisation of the action system (Pufall & Dunbar, 1992). The present data confirmed this contention for grasping.

The ratio between cube and hand size can serve as a control parameter for the phase transition from one-handed to two-handed grasping. This suggestion is supported by the presence of sudden jump, enhanced variance, multistability and hysteresis.

The Van der Kamp et al. (1998) study suggests that the stability properties of the grasping action do not increase with age. For instance, there is no noticeable difference in enhanced variance between the age groups and for all age groups, the variance increases before the 'transition cube', and decreases quickly thereafter. Furthermore, Hock and co-workers (Hock, Kelso & Schöner, 1993) as well as Kruse and co-workers (Kruse, Strüder & Stadler, 1995) have argued that the magnitude of hysteresis is correlated to the stability of the system: a greater magnitude indicates that fluctuations are reduced. These fluctuations can result in spontaneous changes. Reduction of fluctuations indicates that the system becomes more stable. The findings that no difference in magnitude of hysteresis was found between the age groups and could indicate that the stability of the grasping patterns remains constant during childhood. In order to confirm this contention a more extensive experimentation and analysis is needed. For instance by using perturbation studies, more insight can be acquired in the role of kinetics variables like object mass, shape, texture or variables like distance to the object and postural orientation, in the development and stability of prehensile pattern.

One of the cornerstones of ecological psychology is that information is regarded as directly specifying the affordance and guiding the action (e.g. Gibson, 1979, Warren, 1984). The concept of critical ratio's within ecological psychology presupposes a strict one-to-one mapping between information (body-scaled) and action. If one accepts that ratio (body-scaled metrics) can act like a control parameters, dynamic self-organising features are involved in the coupling between perception and action. For example, the hysteresis effect suggests that previous performance influences the ratio, that is the value of the control parameter at which the change between unimanual and bimanual grasping occurs. Thus, on a more macroscopic level the same ratio is accompanied by different grasping patterns. The present grasping data show that a more flexible understanding of the coupling between perception and action is apparent in which action is not uniquely determined by information, but dependent upon the dynamics of the fit between actor and environment.

In conclusion, the findings reported provide evidence for robust body-scaling in the development of prehension. Furthermore, the presence of self-organising characteristics like sudden jump, hysteresis, enhanced variance and multistability, demonstrate that the ratio between cube and hand size serves as a control parameter in the transition from one-handed to two-handed grasping. The stability properties of the prehensile action seem to remain constant from 5 to 9 years of age.

Acknowledgements

The paper was written while the first is a research fellow of the Royal Netherlands Academy of Arts and Sciences and the second and fourth author are supported by the Netherlands Organization for Scientific Research (NWO, grant number 575-59-055 and 575-26-002).

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