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Modelling the Training Effects of Kinaesthetic Acuity Measurement in Children

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In previous papers (Sims, Henderson, Hulme, & Morton, 1996a; Sims, Henderson, Morton, & Hulme, 1996b) we have found that the motor skills of clumsy children are capable of significant improvement following relatively brief interventions. Most remarkably, this included a 10-minute intervention while testing the kinaesthetic acuity of the children using a staircase method (Pest). In this paper, we show that Pest testing improves the kinaesthetic acuity of normal children as well. We analyse the available data on the development and improvement of motor skills and kinaesthetic acuity and derive a causal model for the underlying skills. We show that at least three independent cognitive/biological components are required to account for the data. These three components are affected differently by the various interventions that have been tried. We deduce that improvement on a general test of motor impairment can be found as a result of training in kinaesthetic acuity or through other, independent factors.

Keywords: Clumsy children, school children, motor skills, kinaesthetic, modelling.

Abbreviations: Cog/Aff: cognitive-affective training ; DCM: Developmental Contingency Model; KAC: Kinaesthetic Acuity Test; KS: kinaesthetic sensitivity; Pest: Parameter Estimation by Sequential Testing; TOMI: Test of Motor Impairment.

Introduction

Kinaesthetic sensitivity is responsible for information about muscle tension, position of body parts, and about the extent, direction, and velocity of movements. Research undertaken in both Perth and London throughout the 1980s by Laszlo and Bairstow concentrated on the role of kinaesthesis in motor development. One main concern of these researchers was the absence of a suitable means of diagnosing children's kinaesthetic problems, which led to the development of the "Kinaesthetic Sensitivity Test" (Laszlo & Bairstow, 1985).

Although the Kinaesthetic Sensitivity Test is comprised of two tasks, the one that has generated the most interest is the Kinaesthetic Acuity Test, or KAC. This task is designed to be centred exclusively on the kinaesthetic modality, as the child is required to discriminate the heights of two inclined runways, with vision excluded by a masking box and arms guided passively by the tester. Thus, KAC performance is claimed to be solely dependent on the child's ability to use the available kinaesthetic information about the location and movement of his or her arms.

The impetus for the present study stems from an area of debate based on the assessment protocol of the KAC. The standard test adopts the Method of Constant Stimuli, a method that provides fixed settings and a standard number of trials. The Constant Stimuli method was developed for determining sensory thresholds in adults (see Woodworth & Schlosberg, 1954). Normally, stimuli have values such that performance is spread around the subject's threshold, which is usually defined as 75% correct for a two-choice task. However, Laszlo and Bairstow adapted it in order to make the length of the KAC test practical for use with children and, therefore, they settled on using only two angles, 3 and 5 degrees (or 4 and 7 degrees for the youngest subjects) for the runway settings. More recently, a group of investigators in Sheffield have questioned the suitability of Laszlo and Bairstow's method for assessing KAC. Their main criticism is that the limited settings offered during the KAC render the measurement insensitive to variation in ability among children (Doyle, Elliot, & Connolly, 1986), pointing out that, at such fixed and difficult settings, many children receive stimuli below their detection thresholds and, therefore, they must simply be guessing. This would apply equally to a child who can discriminate height differences at, say, 10 degrees as to a child who

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is having problems with differences as large as, say, 20 degrees.

The root of this controversy appears to lie with the conflicting requirements of diagnosis and measurement. Laszlo and colleagues, on the one hand, were primarily interested in designing a diagnostic tool and the test was suitable for identifying children with kinaesthetic problems. Doyle et al. (1986), on the other hand, wanted to detect developmental differences in kinaesthetic acuity between children. Consequently, they used an alternative method for measuring thresholds known as "Parameter Estimation by Sequential Testing" or Pest (Pentland, 1980; Taylor & Creelman, 1967). They argued that the Pest gives a good estimate of detection thresholds and yet still maintains sufficient economy for it to be practical for testing children. The principle of this procedure is that stimulus values are changed in a stepwise fashion, as a function of a subject's detection rate, such that the values approach the individual's threshold as the test progresses.

Elliot, Connolly, and Doyle, (1988) have already applied the Pest in testing children on KAC to a subset ($N = 31$) of their original sample, and their results showed an improvement in Pest scores with age. However, Pest scores failed to correlate with those obtained using the Constant Stimuli procedure. This is odd because Kinaesthetic Acuity norms also show that children perform better with increasing age (ages ranging from 5 to 12+). Therefore, with a fairly broad sample, one would expect at least a significant age-related correlation between the two methods. It would certainly be the case that the two measures would fail to correlate if one of them involved many children responding at chance, as claimed by Doyle (personal communication). However, Kinaesthetic Acuity norms show that at least 80% of 7- and 8-year-old children do perform above chance and it is not clear what is unusual about the Elliot et al. (1988) sample.

A possible explanation for why the two methods failed to correlate is provided in two assertions made by Bairstow and Laszlo (1986). First, they proposed that Pest acts as a form of training procedure. The Laszlo training procedure for kinaesthetic acuity involves a much wider range of stimulus settings than is offered during the standard KAC. Moreover, an important feature of this training is that it is spontaneous and adaptive: it starts off with easy discriminations and the difficulty is increased at a rate that is dependant on the success rate of the child. Such a procedure ensures that the child is minimally exposed to failure and has the opportunity to monitor his or her progress. Similarly, for Pest, in aiming to find the individual child's approximate threshold, there is usually an overall progression from simple to more difficult settings. The second assertion of Bairstow and Laszlo was that "the effect of training and the degree of retention of a trained ability varies from subject to subject". Thus, if such Pest-induced training influences do occur, we can see how a low relationship between Pest and constant stimuli scores might arise due to individual differences in susceptibility to Pest training effects. The first of these assertions can be supported with recent evidence by Sims et al. (1996a), who, in attempting to replicate the Laszlo training, substituted a version of the Pest procedure to assess KAC in clumsy children, only to find that the control group, who were not given formal training, also improved both in kinaesthetic acuity and in other motor skills, as assessed by the Test of Motor Impairment (TOMI; Stott, Moyes, & Henderson, 1984). This result could be attributed to the incidental training influence of the Pest method because, in Sims et al. (1996b), control children assessed using the Constant Stimuli method did not make any such improvements. Thus, not only did Pest constitute a form of training, it appeared to be so effective as to occlude any effect of a formal training programme. This finding is remarkable, as it implies that children's motor difficulties can ameliorate after just a single 10-minute session. Nevertheless, unlike Doyle et al. (1986), Sims et al. (1996a) did find a correlation between the Constant Stimuli and the Pest scores of the clumsy children in their sample ($r = .67$). However, the need for further investigation of the Pest method is clear: there are no normative data on Pest scores, and, given that the Sims et al. (1996a, b) findings can only be generalised to a small section of the population, specifically to children with movement difficulties, we need a study that investigates whether the training effects of Pest apply to a normal sample of children. Further to this, we are not aware of any cognitive analyses of the skills underlying the various tasks that would help us understand the nature of the relationship between KAC and TOMI, the test used to assess motor performance. In addition it is unclear what it might be that changes as a result of various kinds of training.

To investigate these questions, we obtained a sample of school children with mixed motor abilities and with ages spanning over a 2-year range and assessed their motor skills. Each child was then tested and retested 2 weeks later on the KAC using a version of the Pest procedure. The training potential of Pest can be investigated by looking at whether performance becomes more successful both across testing sessions and possibly also within sessions, either for the sample as a whole or for particular groups of children.

Method

Subjects

Altogether, there were 46 children tested (22 girls and 24 boys), whose ages ranged from 6 years 11 months to 8 years 11 months (mean age: 8 years 5 months). These children were taken from four classes of a mainstream primary school, located in a middle-class area of North London. All third- and fourth-year children attending this school were tested, except for two children who had known physical abnormalities (one with grommets and one visually impaired), those who were absent from school ($N = 6$), and those whose parents refused consent or did not return the consent form ($N = 7$). There were no children in the latter group who were thought by their teachers to be clumsy.

Design and Procedure

Children were seen individually by the experimenter and testing was carried out in a small office and an adjacent corridor (used for ball and balance tasks of TOMI—see below).

Time 1 (*T1*). To obtain a baseline measure of each child's motor performance, the TOMI (Stott et al., 1984) was first

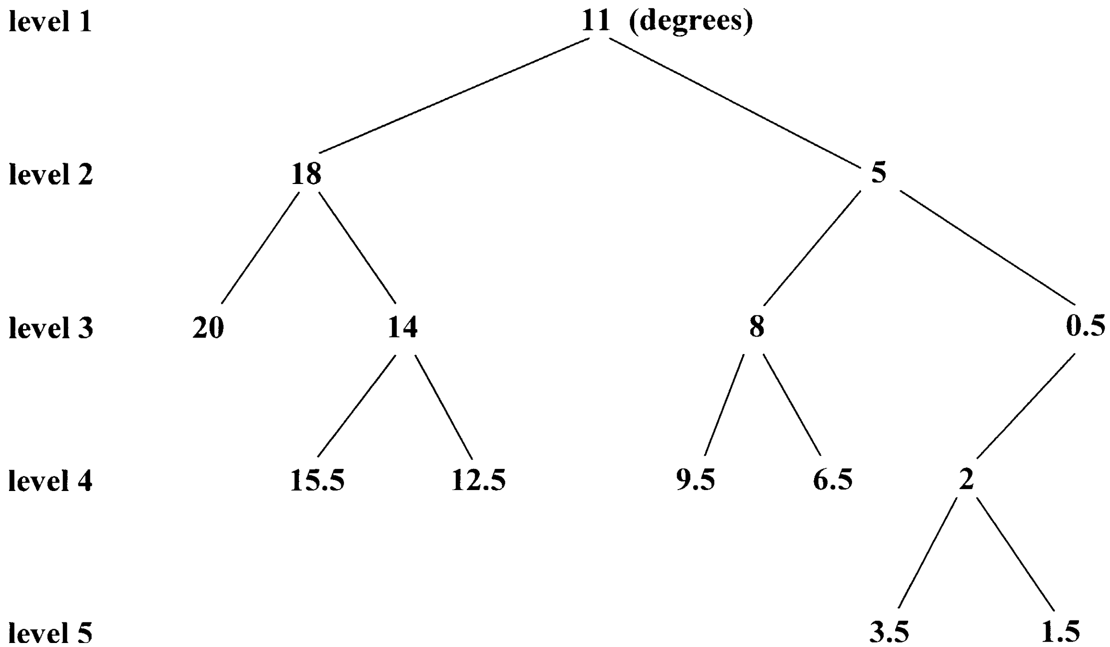

Figure 1. Pest TREE—angle of separation of the runways at each level of testing as a function of the child's success or failure at the previous level.

administered to each child[1]. The TOMI involves eight separate tests: three tests of manual dexterity, two of ball skills, and three balance tasks. An overall score can be obtained, with higher scores (max. 16) indicating greater degrees of motor impairment. The TOMI is a screening test for motor impairment rather than a measure of general motor skill. We used it here partly because it had been used in the previous experiments and partly because no other convenient instrument is available for children.

To test the KAC, the child was introduced to the apparatus and procedure in the standard way as described below. This part of the test is referred to as the *familiarisation phase*. Next, for the *test phase*, we ran the KAC on the subjects, but substituted a version of the Pest method instead of using the standard Constant Stimuli procedure.

Time 2 (*T2*). Two weeks later, the same subjects were seen again individually by the experimenter and were retested on the KAC with the Pest method. The procedure was the same as for the first test, except that the *familiarisation phase* was shorter.

KAC procedure using Pest.

(1) *Familiarisation Phase*: The child was seated opposite the experimenter (KS), who said that she was interested in how well the child could feel where her/his arms were and where they were moving. The experimenter then demonstrated how the two pegs could be moved independently up and down the runways. One runway was set at about 4 degrees and the other was set at 20 degrees. The child was asked to hold the pegs lightly whilst E placed her hands over the child's hands (see Appendix A). At first, the child was able to see the movements of her/his arms. The experimenter pulled the child's hands (over the pegs) up to the top at a steady speed. The child had to indicate which peg went up the highest with a wiggle of a finger on the chosen side. If this proved to be difficult, the child tilted her head over to indicate her choice. Then, the procedure was repeated with runway differences reduced slightly. Next, a masking box was introduced and the trials were repeated with vision excluded, reversing the side of the highest setting for each trial. Praise was given throughout the test regardless of the child's actual performance, though where incorrect responses were made the praise was noncommittal with respect to the response (for example, "OK" rather than "right" or "good"). Trials were repeated if vague or incorrect responses were made. Although occasionally a subject continued to give incorrect judgements on trials using the masking box, E only proceeded to the *test phase* of KAC once she was satisfied that the child had clearly understood the requirements of the task, namely that the arms were to be moved passively, that no vision was to be used, and that the child was to respond appropriately without prompting. The length of the *familiarisation phase* varied between 3 and 14 minutes, depending on the requirements of the child.

(2) *Test Phase*: The child was asked to discriminate between runway heights with vision excluded as in the second part of the *familiarisation phase*, except that the Pest method was used to determine stimulus values. The principle of the Pest is that the frequency with which the subject detects a difference at a given setting determines the next change (increase or decrease) in stimulus values to be offered. Therefore, it serves to home in on the threshold value for that child. We chose to start off at a fairly intermediate setting: a difference of 11 degrees between the runways. All subsequent settings were determined by the ongoing performance of the individual child, with repeated success at a setting being followed by a smaller separation of the two runways and repeated failure by a larger separation. The magnitude of the change in settings was approximately half of the mean of the highest setting failed and the lowest setting passed. For subjects who fail or pass a setting, the next setting up or down is shown in the full decision tree used in the current study (Fig. 1). Using this tree, the maximum number of different settings for each subject is five and given that children could remain at the first level if they neither pass nor fail at the

[1] This test is now known as the Movement Assessment Battery for Children (Henderson & Sugden, 1992).

Table 1
Pest Procedure: Total Number of Correct Trials at a Particular Angle of Separation for the Given Outcome

Trial[a]	Failure[b]	(Continue)[c]	Success[d]	End test
1	—	0,1	—	—
2	—	0,1,2	—	—
3	0,1	2,3	—	—
4	2	3	4	—
5	—	3,4	—	—
6	3	4,5	—	—
7	4	5,6	—	—
8	5	6	7	—
9	—	6,7	—	—
10	6	7,8	—	—
11	7	8,9	—	—
12	8	9	10	—
13	—	9,10	—	—
14	9	10,11	—	—
15	10	—	—	11,12

The angle of separation on the next trial is reduced following success and increased following failure. For example, with only one response correct from the first three trials at a particular angle, the subject would have failed. With all of the first four correct or seven of the first eight trials, the subject would have succeeded at that angle.

[a] Number at any one angle (max = 15).

[b] Increase angle of separation.

[c] Continue at same angle.

[d] Decrease angle of separation.

first setting, then the minimum number of possible settings is one.

The procedure was as follows: The child was tested at 11 degrees and if successful at this level, the setting was reduced to 5 degrees (second setting). If the child failed at this angle the settings moved to 8 (third setting) and then to 9.5 or 6.5 (fourth setting) according to success or failure. On the other hand, children succeeding at 5 were given 0.5 and then 2 and then 3.5 or 1.5, again depending on success or failure. The eventual threshold separation would be the average of the lowest setting passed and the highest setting failed or the level at which there was no further change in stimulus value due to the child wavering between upper and lower bounds for a maximum of 15 trials at one level. For example, if the child passed at 11, failed at 5, passed at 8, and passed at 6.5, the final score would be $(5+6.5)/2 = 5.75$, rounded to 6. However, if the child passed at 11, failed at 5, and then neither passed nor failed at 8, the test would terminate at this point, with the final score simply being 8. The number of trials at each setting depended on the criterion calculated from the formula given by Taylor and Creelman (1967). The relationship between performance at a particular setting and the direction of change of settings can be seen in Table 1. The minimum number of trials for success at any setting is four. One error during the first four trials leads to seven having to be correct in the first eight. To fail at any one setting there have to be at least two errors in four trials or three in six trials, and so on.

Throughout the sessions, positive encouragement was given both nonverbally (reassuring eye contact and smiles) and verbally ("good", "well done", "yes", and "OK"). This was not intended to have a training function, but was intended to keep the child focused on the task.

Results

Are the Samples Representative?

First of all, we needed to confirm that our samples were representative of this age range in terms of level of motor skill. Scores on the TOMI spanned the entire range (lowest = 0, highest = 16), with most scores clustered at the bottom end of the scale (skewness = 2.84, median = 2). The distribution of TOMI scores is, in fact, similar to the standard scores obtained from the larger British/American-Continent samples (Stott et al., 1984), with 78% of the present sample having a low level, if any, of motor handicap (scores between 0 and 3.5), and 7% of children (3 subjects) receiving scores of 6 or more, indicating very serious motor problems.

To see whether motor abilities in general are a good predictor of Pest scores, we correlated TOMI with Pest scores at T1. A significant correlation (Spearman $\rho = .40$, $p < .01$) shows that subjects with better performance on TOMI did better on the first KAC session.

Does KAC Improve with Pest?

We looked at three aspects of the data in answering the question of whether Pest serves to improve children's KAC performance. Initially, we compared Pest performance at *Time 1* (T1) with that at *Time 2* (T2) to see if there were any improvements occurring across tests. Then, in order to examine these improvements more closely, two further analyses were carried out. One of these involved an investigation of the training profiles to see whether subjects showed improvements occurring within a test. The other looked at possible individual differences in the extent to which children could be trained as a result of the Pest procedure.

Comparison of T1 with T2. There was a decrease in mean kinaesthetic acuity Pest scores from T1 to T2 (8.1 to 5.2). T1 was higher (poorer) for 34 subjects, there was no difference for 8 subjects, and T2 was poorer for only 4 subjects. This effect was highly significant [$F(1,45) = 32.7$, $p < .0001$]).

Training profiles. In addition to this overwhelming evidence for improvement between T1 and T2, we also wanted to know whether there was evidence of improvement occurring during the testing procedure. Accordingly, we looked for evidence of training at T1 within the subjects" training profiles, as they travelled along the Pest tree. Sixteen subjects showed profiles which suggest such training. There appear to be two sources of evidence:

(1) Where the child does better on later, harder trials than at the initial setting of 11 degrees. Nine subjects showed this indication of training (average trials: 11 degrees [7 pass/1 fail], 5 degrees [3 pass/3 fail], 8 degrees [4 pass/0 fail], 6.5 degrees [4 pass/0 fail]).

(2) Where a child fails at 11 degrees, but later, at a setting which is only marginally easier, passes without a single error. Seven subjects showed this evidence of direct training (average trials: 11 degrees [2 pass/2 fail], 18 degrees [4 pass/0 fail], 14 degrees [4 pass/0 fail], 12.5 degrees [4 pass/0 fail]).

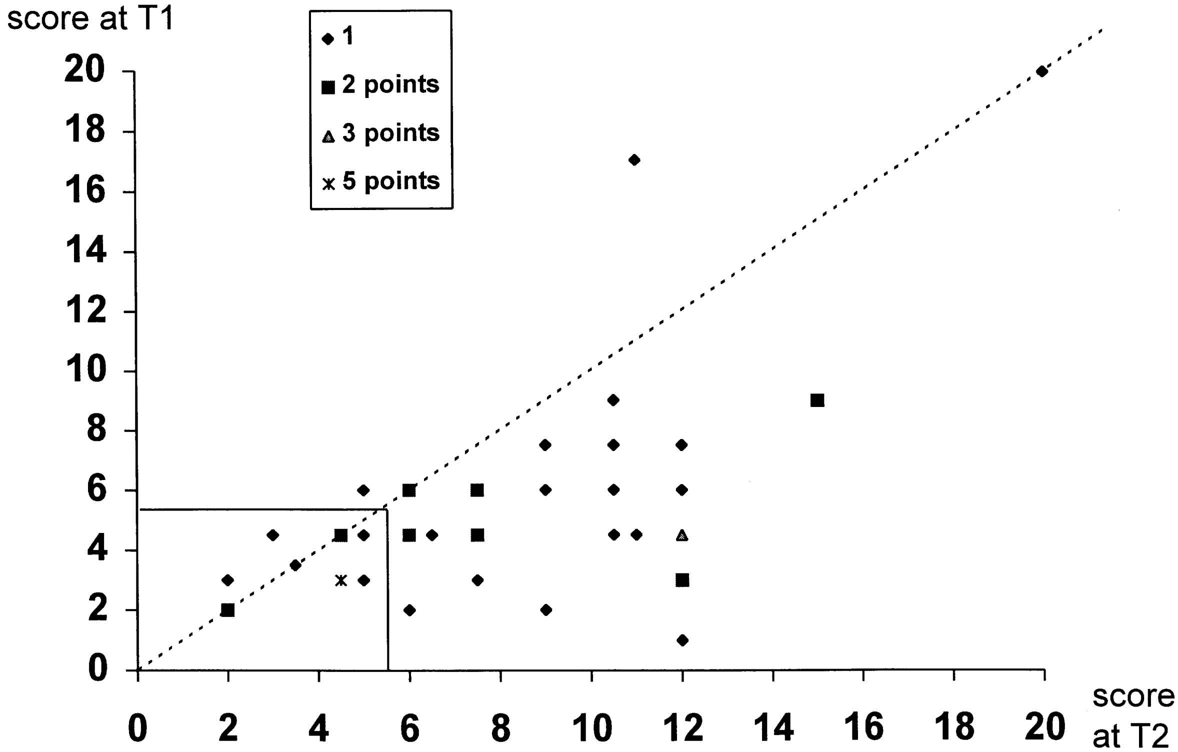

Figure 2. A scatter plot of Pest scores at T1 against those at T2. The T1 = T2 line is dotted. Points below that line show improvement from T1 to T2. We assume that a threshold of six constitutes peak effortless performance for these children and variation below six will depend on factors unrelated to KAC ability. Scores within this band at both T1 and T2 are enclosed in the solid rectangle.

Table 2
Characteristics of Pest Performance for TOMI Subgroups

	Pest at T1			Optimum level at	
TOMI subgroups (*N*)	Mean	*SD*	Range	T1	T2
0–1.5 Normal (21)	7.2	(3.9)	2–15	11 (53%)	18 (86%)
2–3.5 Minor (15)	7.5	(3.2)	2–12	7 (47%)	13 (87%)
4–5.5 Moderate (7)	9.1	(3.4)	4.5–12	2 (29%)	7 (100%)
6–16 Serious (3)	14.3	(4.9)	11–20	0	0

Extent of training. Figure 2 is a plot of Pest scores at T1 against those at T2. Two of the 12 subjects who did not improve were very clumsy (with TOMI scores of 6 or greater). The other 10 of these 12 subjects already had scores of 6 or less at T1. Thus, of the children who obtained a score of 6 or less on T1, 10 improved, 7 had the same score, and 3 got worse. Furthermore, none of these subjects obtained a score worse than six on T2. We hypothesise that a threshold of six constitutes peak effortless performance for these children and scores below six will depend on factors unrelated to the kinaesthetic ability underlying KAC, such as a general testing factor like attention and/or a more specific effect like a lateralised response bias and/or an artefact of the inaccuracy of small angle settings due to possible minor geometric imperfections in the apparatus. For this reason, in subsequent analyses of scores, we separate those performing at this optimum level of ability (one to six range) from those subjects who score above six at T1. At T1, 44% of the subjects score at the optimum level.

Looking at those subjects who passed at the initial setting at T1, 20 out of 33 reached optimum performance at T1. The remaining 13 subjects in this group showed an improvement from T1 to T2, with 10 of these subjects reaching optimum at T2. For those subjects who failed at the initial setting at T1, 8 out of the 13 reached optimum at T2, and of the 5 remaining, only 2 subjects (both very clumsy) failed to show any improvement across tests.

Are There Other Factors which Determine Variation in Pest Trainability?

Although all but two subjects improved by T2, six subjects showed improvements that did not reach optimum ability. Pest clearly has a training effect, and yet there do appear to be some individual differences in sensitivity. We examined the two factors of motor ability and age to see what influence they may have had.

Effects of general motor abilities? We looked to see if there are differences in Pest training between clumsy and well-coordinated children. We have already shown that

TOMI correlates with Pest at T1 ($\rho = .40$). However, as TOMI is a test of impairment, we expect a large number of children to perform at ceiling on this test. Therefore, to look more closely at the nature of this relationship, we decided, on the basis of the classifications used by Stott et al. (Henderson revision, 1984), to divide subjects into four subgroups of motor ability. Twenty-one subjects are seen to have "average motor competence" (Normal: scores between 0 and 1.5), 15 subjects are classified as having "minor problems" (Minor: scores between 2 and 3.5), a further 7 are labelled as having "moderate problems" (Moderate: scores between 4 and 5.5), leaving 3 subjects with "definite problems" (Serious: scores of 6+). Table 2 shows that average Pest scores at T1 were higher for subgroups with higher TOMI scores, as one might expect from the significant correlation between these variables.

Normal, Minor, and Moderate groups cannot be differentiated significantly on their ability to reach the optimum level at T1 (scoring at six or less on Pest), suggesting that, at least for these three groups, the training effects of Pest are not strongly affected by initial ability or overall motor competence. In fact, the only evidence of motor competence influencing Pest training is from subjects with very extreme motor impairments. None of the three subjects with Serious TOMI scores were able to reach a score of six on the Pest, with two of these subjects showing no improvement at all.

Another finding (also see Table 2) is that five of the subjects scoring either Normal or Minor TOMI are still incompletely trained after the second test (scoring above six at T2), suggesting that other factors may influence Pest training. We return to this result again in the next section.

Age effects? As Doyle et al. (1986) found an effect of age on Pest performance, we looked to see whether there were any effects of age on Pest improvement in this study. Altogether, the ages of subjects ranged from 6 years, 11 months to 8 years, 11 months (mean: 8 years, 5 months). There was a significant Pearson correlation between T1 Pest scores and age in months ($N = 46$, $r = -.33$, $p < .05$).

Given the similarity in starting ability and training profiles between Normal and Minor subgroups, we combine these two groups to look at the effects of age. For these subjects, the mean age for those who did reach peak Pest ability is 97 months compared with 91.8 months for those 5 subjects who did not reach peak Pest ability. An independent *t*-test for unequal variances shows that this difference is significant ($t = 3.71$, $df = 14.71$, $p < .002$), and this effect was also confirmed with a Mann–Whitney test ($U = 23.5$, $p < .05$).

Discussion

The main purpose of this study was to see whether a stepwise protocol, Pest, designed with the intention of assessing kinaesthetic acuity, could have the incidental effect of training children's kinaesthetic acuity. We were interested in whether such effects could occur in a normal population as well for clumsy children and whether there were differences between children in their sensitivity to such effects. We found strong evidence in support of the Pest training hypothesis and, although there were two children who seemed to be immune to the effects, Pest trainability appears to be present in children of wide-ranging abilities.

The main finding was that Pest scores were significantly better on the second test than on the first. In fact, of the subjects who did not reach peak ability (6 degrees or better) at the first test, all but two achieved better scores on the second test. This looks like strong evidence indeed for claiming that using a Pest procedure to test kinaesthetic acuity can by itself bring about kinaesthetic training effects. It may be argued that the enhanced scores at retest are simply a reflection of children's increased familiarisation with the task. However, we have chosen to reject this account of the data for two reasons. The first is that an extended familiarisation phase was given to all subjects to ensure that they fully understood the instructions and had received sufficient practise with the equipment. The second reason is that there is independent evidence to show that a group of clumsy children given KAC using the Constant Stimuli method do not show any improvement at retest after a similar 2-week interval (Sims et al., 1996b). This evidence provides support for the claim that it is something about the use of Pest as an assessment procedure for kinaesthetic acuity that is causing the improvements.

Furthermore, the present study provides further evidence to show that the Pest method was producing genuine and substantial training effects. First, 16 subjects showed direct evidence of training occurring within the first session: doing better towards the end of the test than at the beginning, despite the fact that all the children had received the extended familiarisation phase before the actual testing commenced. Second, most children (79%) were able to reach an optimum level of performance by the end of the study. The fact that eight of these children had begun the first testing session very poorly is strong evidence to support the training hypothesis as opposed to any suggestion that the improvements were merely superficial. These children were brought to a peak level of KAC ability after just two sessions with the Pest.

The speculation that there may be broad individual differences in trainability through Pest (Laszlo & Bairstow, 1985) gets only weak support from the present findings: over a third of our normative sample performed very poorly on Pest from the outset of the study, failing at 11 degrees. Whilst general motor abilities were varied, all but two children did improve after being tested with Pest. Although variability in the speed and extent of improvement could be at least partly accounted for by general motor ability and age, the methodology of Pest appears to have exacerbated these differences, so that it is not clear what influence these particular variables had: younger children and clumsy children are more likely to fail at the first level and this strongly influences the final score by setting the boundary above or below which subsequent levels can be offered. In the present study, children failing at 11 degrees could never achieve a threshold score lower than 12, whereas those passing at this initial level were already protected from receiving a final score any higher than 10.5. However, two out of the three subjects with very poor TOMI scores did not show any improvement, which is in accordance with the results of Sims et al. (1996a), which also showed that the most seriously motor impaired subjects did not improve in KAC following Pest. Thus, children with extreme degrees of motor impairment seem insensitive to the Pest training effects. Furthermore, despite this study having an even narrower age range than Doyle et al. (1986), age was shown to be a limiting factor in Pest induced training, which is largely independent of motor ability. In summary then, Pest training occurs for almost all subjects who require it, with some variability occurring as a function of general motor ability and age.

The mechanism of learning is not clear. We assume its basis is the spontaneous integration of kinaesthetic feedback, though it is possible that verbal cues were used as well, in spite of our trying to minimise these. These could have been used differentially between the two sessions. It remains to be discovered whether learning during Pest would be enhanced or inhibited by explicit positive and negative feedback.

The next step, then, is to see how this information about Pest training effects ties in with what we already know about children's kinaesthetic acuity training and performance. It has already been established that certain types of procedures can lead to improvements on motor tasks over a very short period of time. In Sims et al. (1996a) we found that clumsy children can improve their general motor skills, as measured by TOMI, after the Laszlo kinaesthetic training programme and also after the Pest procedure, without any formal training. In Sims et al. (1996b) we found equivalent training effects by using an intervention procedure that was designed to minimise the kinaesthetic component. This method, known as the "cognitive-affective" procedure, closely matched the Laszlo training on certain features that were intended to optimise the child's motivation and encourage perseverance. The fact that the Laszlo training and this cognitive-affective method produced similar outcomes to the Pest implies that there are factors, common to these three methods, which are responsible for showing motor improvements. One way of examining these factors is to separate the cognitive components from the performance components within the same model. This we attempt to do in the final section by using the principles of two types of cognitive models: the Developmental Contingency Model (Morton, 1986) and the Causal Model (Morton & Frith, 1995).

A Model of KAC

We have established a number of key facts from Sims et al. (1996a, b) and the present results. In some cases the numbers of subjects are very small and it is possible that in the future, with the accumulation of more data concerning extreme cases, there might need to be some adjustment to the final model.

(1) On initial testing with a normal population of children, performance on TOMI is correlated with performance on the KAC test, when the Pest method is used (Sims et al., 1996a).
(2) The majority of children do not show general motor problems. Nevertheless, a fair proportion of these children do have scope for KAC improvement (Lo TOMI/Hi KAC). For these children, the effect of using the Pest procedure is to improve performance either during the test itself or in the 2-week interval between the first and second measurement (this study).
(3) For the typically clumsy child, with mild to moderate motor impairments (Medium TOMI/Hi KAC), the full Laszlo training and the Pest procedure can lead to an immediate improvement on KAC and improvement on the TOMI test over a period of several weeks (Sims et al., 1996a).
(4) The cognitive-affective training procedure can also lead to clumsy children showing an improvement on TOMI whilst showing no improvement on KAC (Sims et al., 1996b). However, if these children then receive a session of Laszlo training, they then improve on KAC at a faster rate than they would have done had they not previously been given the cognitive-affective programme (Sims et al., 1996b).
(5) The very small proportion of very clumsy children who have motor impairments of an extreme form (Hi TOMI/Hi KAC) fail to improve or fail to reach peak ability on KAC following the Pest procedure (this study: $N = 3/3$, Sims et al., 1996a: $N = 2/2$), but they do improve on TOMI (Sims et al., 1996a: $N = 2/2$). However, just as for the clumsy children who are less seriously impaired, very clumsy children improve on both KAC and TOMI after training with the Laszlo procedure (Sims et al., 1996b: $N = 7/7$). Moreover, very clumsy children do improve on TOMI following the cognitive-affective procedure (Sims et al., 1996b: $N = 8/9$).
(6) A small proportion of subjects who are not clumsy but have problems with KAC (Lo TOMI/Hi KAC) did not achieve full training after two sessions with the Pest. They are younger than other groups ($N = 5$, this study).

We think that it will be helpful in the analysis of this problem to present the various alternatives within a pair of complimentary frameworks, Developmental Contingency Modelling (DCM) and Causal Modelling. The essence of the two frameworks is to present theories of particular kinds, implicational and causal theories respectively. These frameworks adopt a particular diagrammatic form. They both have the added feature of an explicit separation of the behavioural from the cognitive level. The principal statement in a DCM (Morton, 1986) is that ⟨*X is a prerequisite for the normal development of Y*⟩. An example is:

> a grapheme-phoneme correspondence system is a prerequisite for the normal development of nonword reading (Morton & Frith, 1995)

To date, Causal Modelling (Morton & Frith, 1995), has been used to trace the cause of abnormal development. The principal statement in Causal Modelling is of the form ⟨*the absence of X causes the absence of Y*⟩. Thus:

> the absence of phonological skills causes the absence of alphabetic reading.

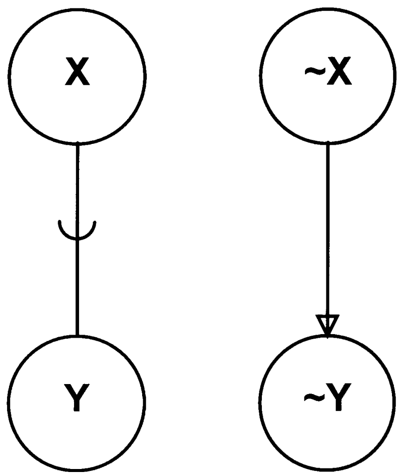

Figure 3. The left-hand component is an element of a developmental contingency model (DCM; Morton, 1985). It is to be read as "X is a prerequisite for the normal development of Y". The right-hand component is the corresponding element from a causal model (Morton & Frith, 1995). It is to be read "the absence of X causes the absence of Y".

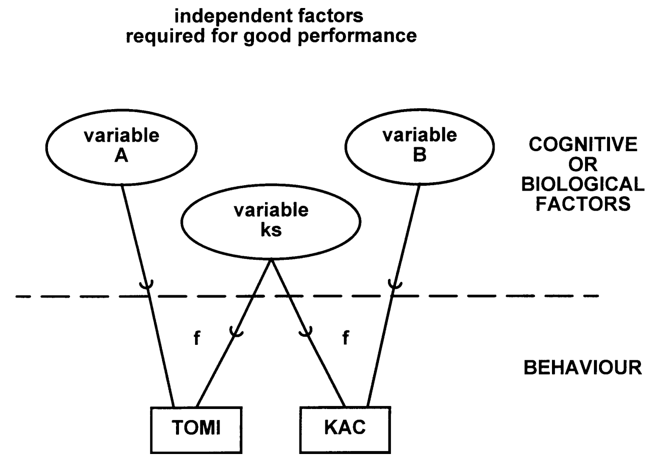

Figure 4. The basic DCM for the tasks used in this and related experiments. A firm separation is made between behaviour, which is observed during the performance of tasks, and the cognitive and biological factors underlying such behaviour. The ability (cognitive or biological), KS, affects the level of performance of both TOMI and KAC. Variables A and B are specific in their influences on individual tasks.

The relationship between the two frameworks is shown in Fig. 3. If there is a contingent developmental relationship between X and Y as in Fig. 3, then it would follow that the absence of X would lead to absence of Y[2]. This is no more than a representation of simple reasoning involving the relation between models of normal and abnormal development. The function of the diagram is merely to clarify and render explicit this reasoning.

In relation to kinaesthetic acuity, we first consider the correlation between the Pest measure of KAC and performance on TOMI. The temptation would be to assume that there is a causal relationship between KAC performance and TOMI performance. Such an assumption violates the basic principle of DCMs whereby all task performance is to be seen as behaviour but all prerequisites have to be couched in terms of cognitive or biological principles. This is because behaviour is inherently transitory whereas cognitive and biological factors refer to states of the organism. We have, then, to postulate biological or cognitive factors underlying KAC performance and accounting for changes in performance.

A second problem is that while there may be tests which do directly measure a single underlying ability, they are rare. Performance on both KAC (measured by either the Pest procedure or the method of Constant Stimuli) and TOMI will be influenced by motivation, for example. Thus, it would be dangerous to assume that either test was a pure measure of some underlying ability even though it is clear that KAC, being a simpler task than TOMI, is more likely to have a strong single component (and no-one would be tempted to claim that bad performance on TOMI causes bad performance on KAC!). What we are required to do is to postulate some underlying ability, the level of which limits both KAC and TOMI performance. In Fig. 4, we distinguish abilities from tasks by enclosing the former in an oval box and the latter in rectangles. In previous writings on causal modelling, we (especially Morton & Frith, 1995) have made the simplifying assumption that underlying abilities are either present or absent. Such a simplification is clearly inappropriate in this case. In Fig. 4, then, we show the connection between an ability, designated as KS (kinaesthetic sensitivity), and performance on the tasks KAC and TOMI with a line marked with an f, to designate a variable function relating the ability-to-task pairs. Clearly there will be other factors contributing separately to performance on TOMI and on KAC and we have indicated those as A and B respectively in the diagram, without saying anything about their properties. Poor performance on TOMI, then, could be due to a weakness in kinaesthetic sensitivity (KS) or because of weakness in the other factors, A. Equally, poor performance in Pest could be due to a weakness in KS or because of poor B. In the analysis that follows, we will refer to levels of ability, with A and KS as either good, medium, or poor and B as either normal (by default) or poor. We will use the same terms to refer to levels of performance on TOMI and KAC. Normal children will be described as having good TOMI, the clumsy population in general have medium TOMI, and a few very clumsy children have poor TOMI. Performance on KAC we will characterise as either good or poor, with the exception of a small group of children to be discussed later. We think that these categories are the minimum we need to explain the facts we have listed above.

In developing the modelling, we choose not to spend time describing the abilities of those children who perform well on both TOMI and KAC. We can only assume that the relevant characteristics of these successful normal children are all good. However, there were several other children in the present experiment, who did not show any noticeable motor impairment, but nonetheless were still poor on KAC. For these children, the effect of testing KAC using the Pest procedure is to improve performance

[2] This simplification ignores the possibility that Y might be achieved by means other than the normal developmental trajectory.

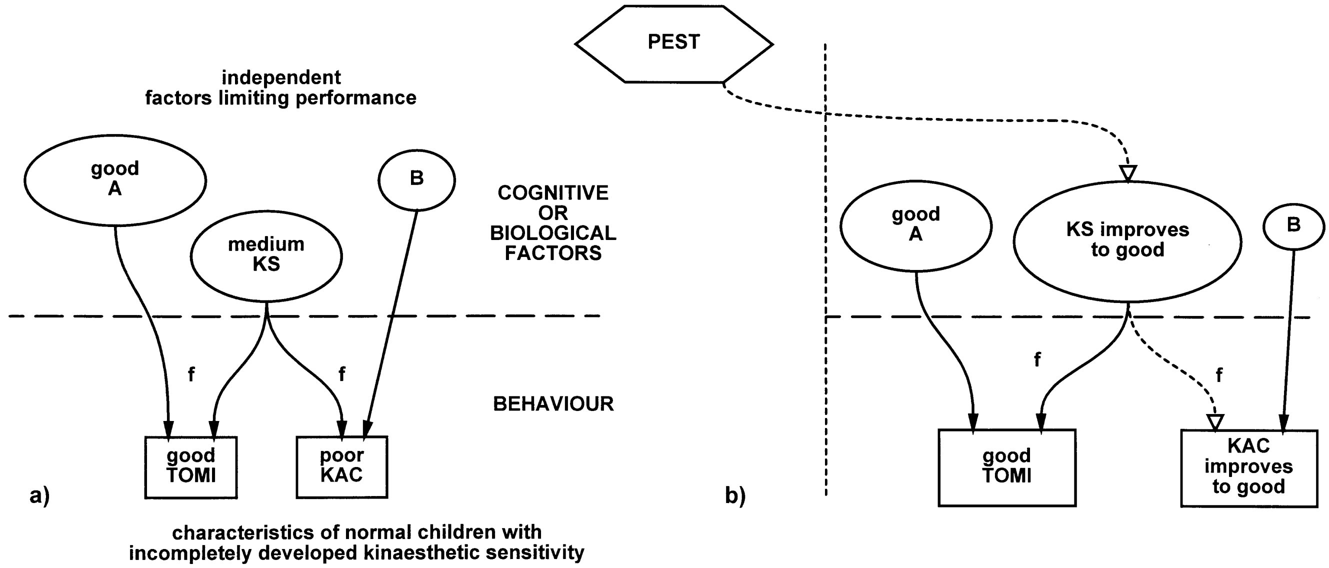

Figure 5. This and the following figures show the states of particular groups of children before and after a particular intervention. In this case, we have the effects of Pest on children who pass TOMI but perform poorly on the KAC test. We deduce that these children have a medium level of KS which improves to good following the Pest intervention. There is a corresponding improvement in KAC performance. Changes in the underlying factors and in task performance are indicated on the right-hand side of the figure with the affected elements indicated by dotted lines and unfilled arrows. All performance requirements, underlying abilities, and training effects are also logged in the various parts of Appendix B.

on KAC, as shown either during the Pest procedure itself or in the 2 weeks following. These children, in the main, have low TOMI (indicating normal motor development) so we might assume that the A factors are good. We rule out any effects as being due to B, because other groups show that Pest has an influence on both KAC and TOMI. The inference, then, for this group of children, is that KS is often good enough to sustain good TOMI performance, but not enough for good KAC. (We show this in Fig. 5a as "medium KS"). Since Pest results in the improvement of KAC, either within a session or between sessions, we suppose that KS must be improved from a medium level of ability to a good one. We have first to represent the Pest training as a causal agent. This we do using a hexagonal box. In Fig. 5a, the subjects are shown as good in A and medium in KS. These abilities are sufficient for good TOMI performance, but not for good KAC performance. The Pest training is shown in Fig. 5b, to the left of a line that separates factors concerning the individual from the environment. The training affects KS and, therefore, the effects are passed on to performance on KAC. Relationships between ability and performance that change as a result of training are shown in the figures with dotted lines and unfilled arrows.

Now we turn our attention to the training effects on clumsy children. We have already established that a medium level of KS is sufficient to allow a good score on TOMI when the A factors are good. Thus, for children with only medium TOMI, we infer that the problem stems from the A factors. (A further constraint is that in modelling very clumsy children, we will want to specify a poor level of KAC—see Appendix B2.) We model the characteristics of clumsy children in Fig. 6. These subjects are shown as medium in A and medium in KS. We define these as sufficient for medium TOMI, but unable to sustain good KAC performance (see Appendix B4 and B5).

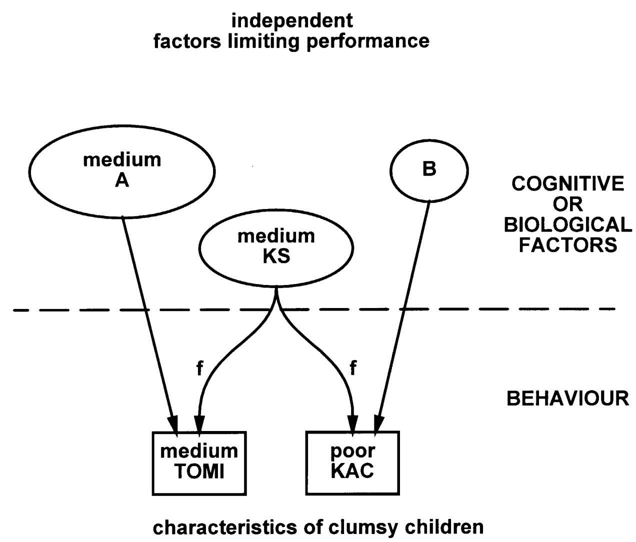

Figure 6. The characteristics of clumsy children with respect to their performance on TOMI and KAC and the state of the internal factors which limit performance on these tasks. The effects of particular interventions on this group of children will be shown in Figs. 7, 8, and 9.

In the second study by Sims et al. (1996b), we found that practice on a variety of tasks, drawing, miming and the pursuit rotor, under conditions that were designed to improve the children's self image and motivation, led to improvement on TOMI in clumsy children. We called this procedure cognitive-affective training. It did not lead to improvement in KAC. With the model in its present form there are two options. The first is that the cognitive-

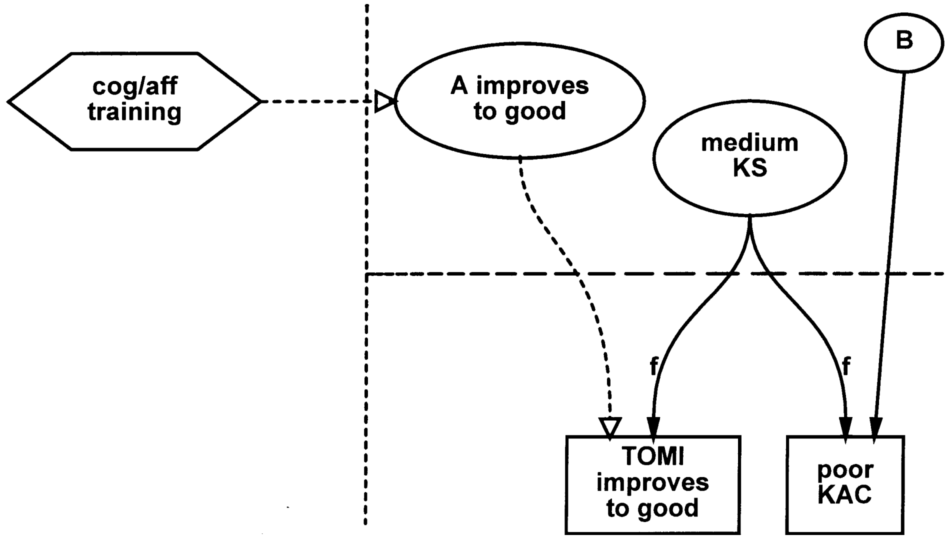

Figure 7. The effect of cognitive/affective training on clumsy children. This training only affects the A factor; consequently, while TOMI improves, KAC is left unaffected.

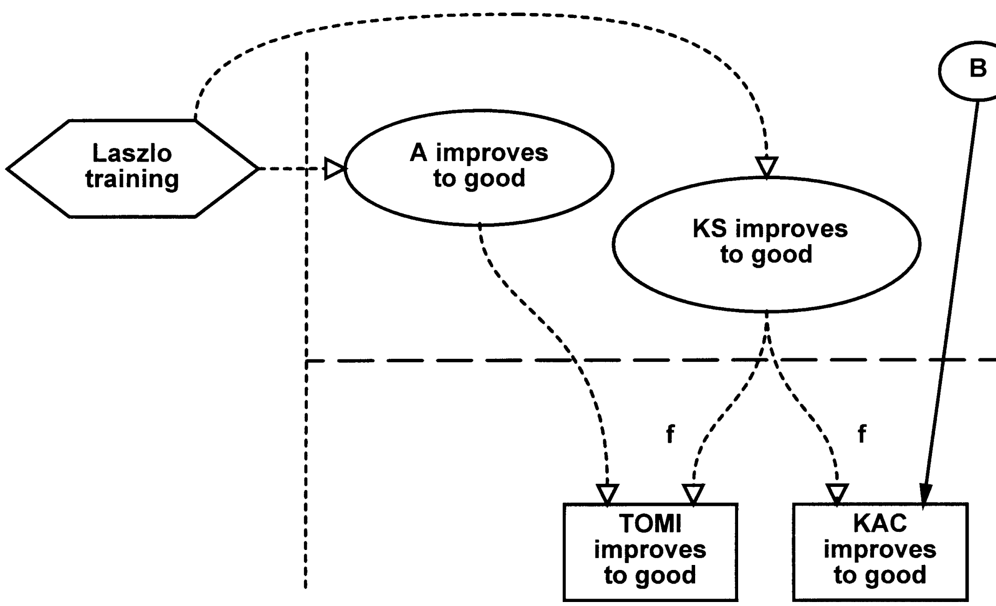

Figure 8. The effect of Laszlo training on clumsy children. In this case both factors A and KS are affected, with consequent improvements in performance on both TOMI and KAC. The same figure describes the effects of running the Pest procedure on clumsy children.

affective training directly improved kinaesthetic sensitivity (KS). Since the cognitive-affective training was designed to have a minimum of reliance on kinaesthesis, we think this implausible. In addition, we note that improvement in KS ought to lead to a corresponding change in performance in KAC for subjects who are not held down by a low level of B. The only other option with the present model is that the cognitive-affective training affects the other factors, labelled A in the figure, and that A and KS interact in a nonlinear fashion to give the improvement found (see Appendix B4). In Fig. 7, then, the cognitive-affective training for clumsy children is shown as affecting only A, so that the effects are passed on to TOMI but not KAC.

Next we can note that the effects of Laszlo training on TOMI in Sims et al. (1996b) were indistinguishable from the effects of cognitive-affective training. First, the magnitudes of the effects were not significantly different. Second, they were qualitatively alike in that the immediate improvement following both kinds of training was on the balance component of TOMI. The most economical hypothesis, then, is that, like the cognitive-affective training, the Laszlo training has an effect on A, and thence on TOMI. The difference between these training programmes is that Laszlo training also leads to an improvement in KAC. This would be effected through a change in KS, for which the Laszlo training is explicitly designed. These interactions are shown in Fig. 8. As with

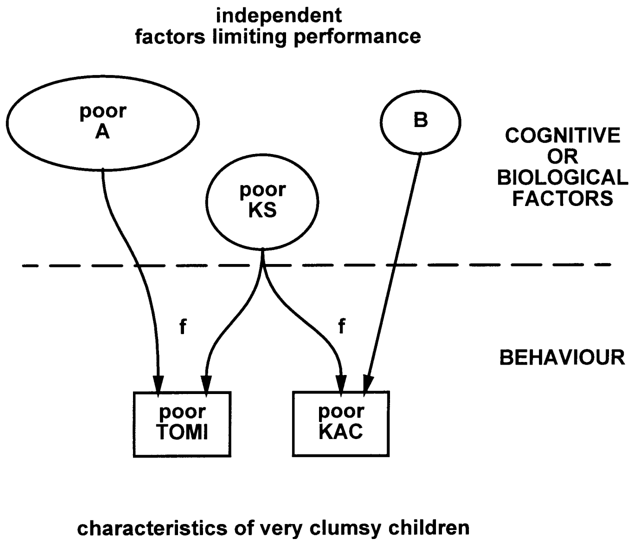

Figure 9. The characteristics of very clumsy children. They differ from clumsy children, as shown in Fig. 6, by being characterised as poor in variables A and KS.

the effects on A, the effects on KS are shown as changing from medium to good.

Clumsy children given cognitive-affective training (Cog/Aff) are improved to good TOMI (see Sims et al., 1996b, for further discussion of this). These children were then faster to train on KAC when given Laszlo training than were the basic Laszlo group of clumsy children. In order to account for this effect, it is necessary to postulate that the Laszlo training has certain resource limitations. In other words, although the factors A and KS are independent, the speed at which the training has an effect on these factors is interactive. The Cog/Aff-trained children only require a change of KS, whereas the basic Laszlo group require a change of both KS and A. Thus, for the Cog/Aff-trained group, as all resources are working to affect KS and none are required to affect A, the simple hypothesis is that training is more rapid than when the resources are divided between both factors.

Next we look at the effects of Pest on clumsy children. Apart from clumsy subjects with very severe motor impairments, significant improvements occurred in KAC in both the present experiment and in Sims et al. (1996a), where improvements were also seen in TOMI following Pest. These effects were similar in magnitude to the Laszlo training and therefore, given that Pest involves the same task as the Laszlo training, the simplest inference is that Pest, as administered by Sims et al., serves to affect both A and KS. The changes taking place through Pest for clumsy children would be the same as those taking place through Laszlo training, shown in Fig. 8. Note that we do not have data on the long-term effects of Pest on clumsy children. Thus, although we have characterised such effects as being equivalent to those of Laszlo training, we may ultimately want to make a distinction between them. The model as we have derived it is only as good as the data we have considered and it may ultimately have to be made more complex.

We can now consider the fifth fact that very clumsy children, with an exceptionally high score on TOMI (poor TOMI), either fail to improve or fail to achieve peak KAC as a result of simply going through the Pest procedure. This was true of the two children scoring at floor on TOMI in Sims et al. (1996a), as well as with two of the three high TOMI subjects in the present study. On the other hand, such children do improve following the Laszlo training programme. The simplest account is that these children have a particularly low level of KS and that the Pest effects are not powerful enough to have a sufficiently large influence on KS. Therefore, when KS is

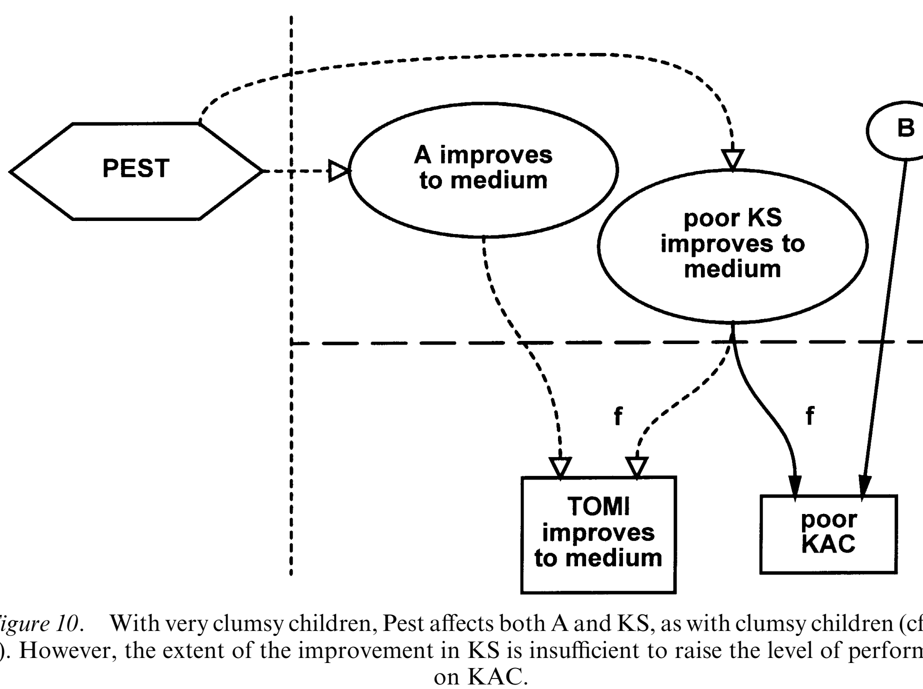

Figure 10. With very clumsy children, Pest affects both A and KS, as with clumsy children (cf. Fig. 8). However, the extent of the improvement in KS is insufficient to raise the level of performance on KAC.

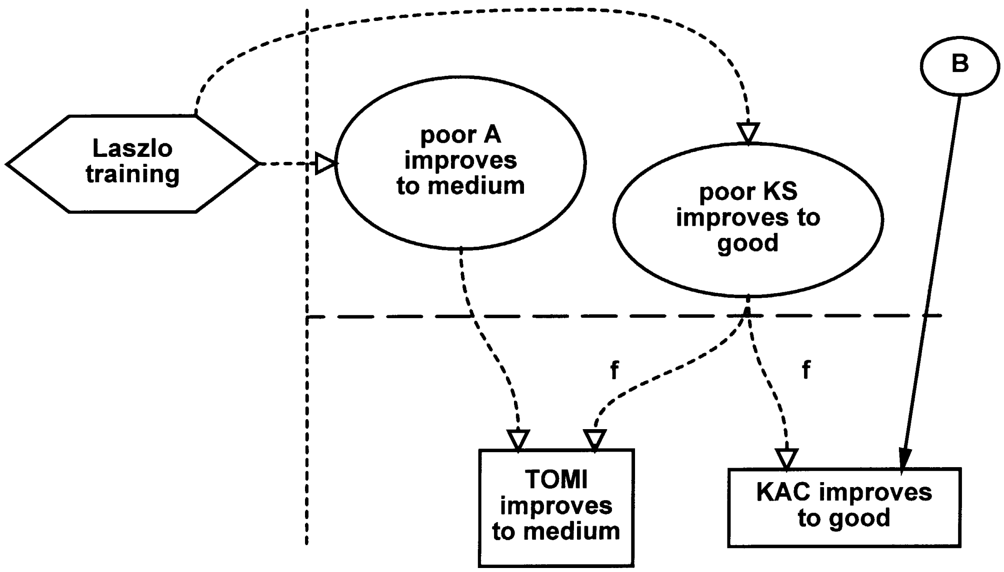

Figure 11. The effects of Laszlo training on very clumsy children. Unlike the other interventions, the Laszlo training changes the level of KS to good, with a consequent effect on performance on KAC tasks.

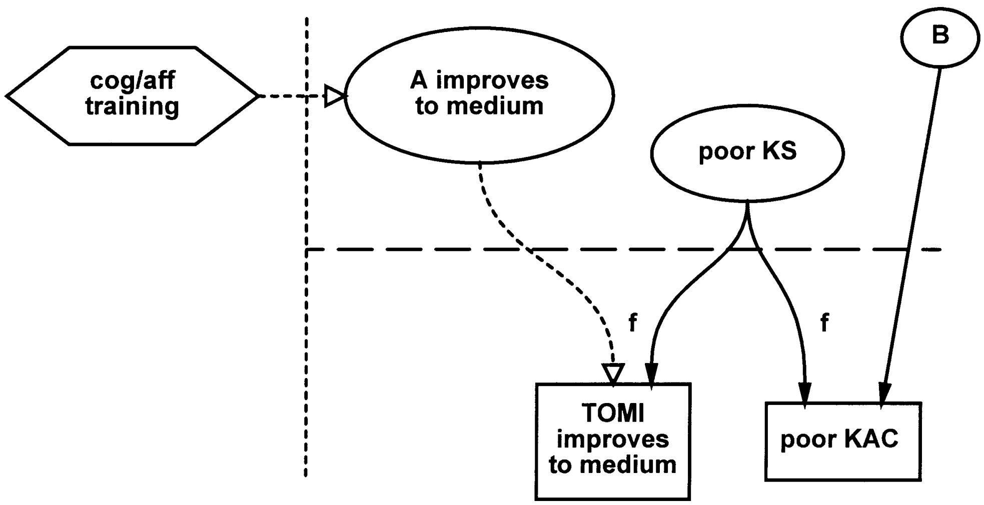

Figure 12. The effects of cognitive/affective training on very clumsy children. This affects A but not KS (cf. Fig. 7).

poor, Pest cannot improve it to a level sufficient to bring about changes in KAC. The full Laszlo programme, on the other hand, has the ability to bring even very poor KS to the level where KAC performance is at peak level. In Sims et al. (1996a), the two very clumsy subjects improved on TOMI following Pest and so it looks as if the Pest procedure had a large enough effect on A to give rise to improvement on TOMI. As the improvement on TOMI is from poor to medium, we are forced to conclude that the changes in A are from poor to medium also. The characteristics of the very clumsy group are shown in Fig. 9. The changes taking place as a result of Pest are shown in Fig. 10. Clearly, more data from very clumsy subjects are needed to make this conclusion secure.

The effects of cognitive-affective training and Laszlo training on very clumsy children (poor TOMI) were the same as the effects of these interventions for the more typical clumsy child (medium TOMI). Moreover, the amount of TOMI improvement was also the same. Thus, those with poor TOMI gained enough improvement in factor A to achieve medium TOMI, but, just as with Pest training, they still failed to attain good TOMI performance. Figure 11 shows the Laszlo training effects on very clumsy children, where TOMI is changed from poor to medium and KAC improves from poor to good. Figure 12 shows the effects of cognitive-affective training on clumsy children, where TOMI is improved to medium and KAC remains unchanged.

There is one remaining observation to account for. This is that some Lo TOMI/Hi KAC subjects in the present experiment did not train fully on Pest. Since we have already established that if A is well developed,

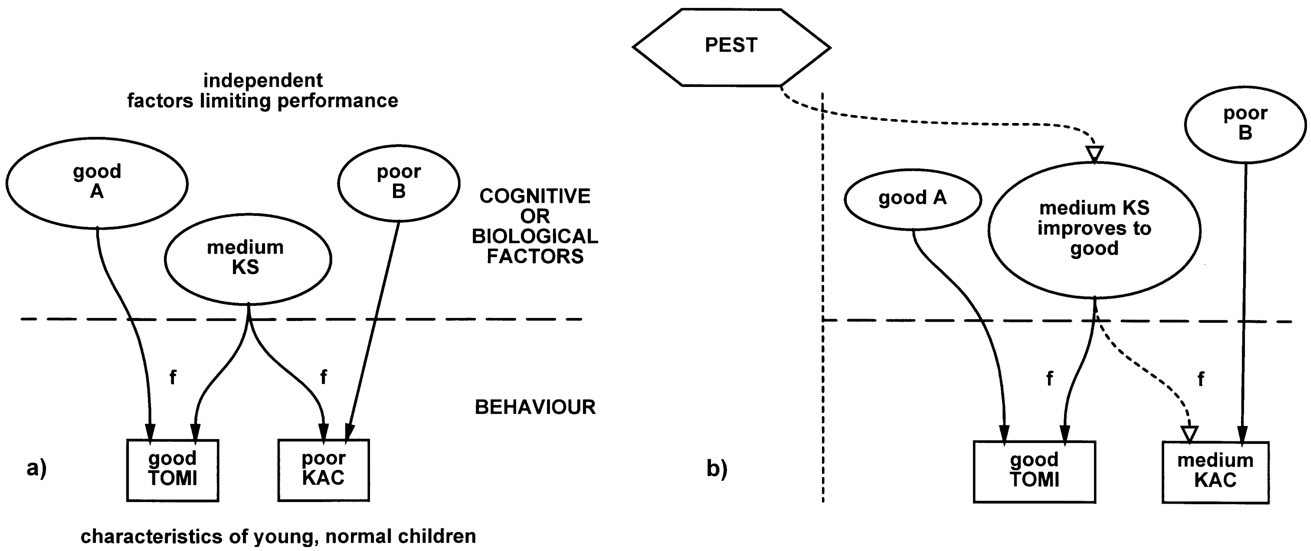

Figure 13. The effects of running the Pest procedure on young normal children. Although the level of KS improves, the state of factor B prevents KAC performance from becoming good.

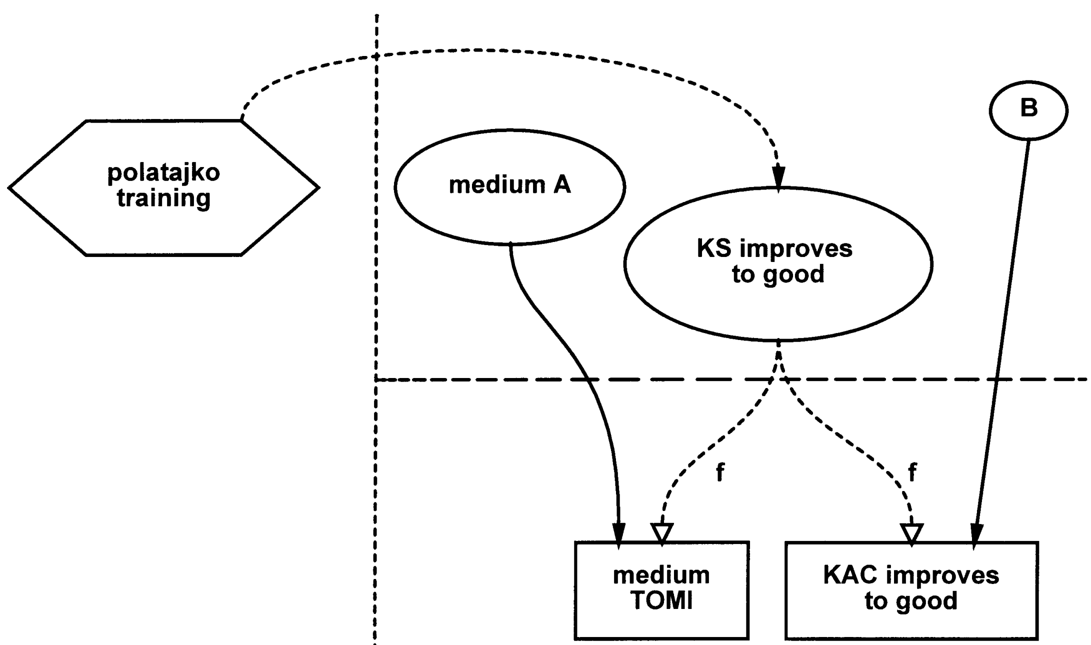

Figure 14. The effects of Polatajko et al. (1995) on clumsy children. The Laszlo procedure was used with variants. This had the effect of improving KS but leaving A unaffected. Performance on KAC improved but TOMI performance remained unchanged.

TOMI performance can be good even when KS is lower, at first the problem seems to be that of KS ability. However, given that Pest leads to improvements in KAC when KS is medium, but no improvements when KS is poor, the small improvements shown by these subjects suggests that the limitation for them is in the factor B. These children are younger than other groups and, therefore, we imagine that the limiting factor B develops with age. Figure 13a shows the characteristics of young subjects and Fig. 13b shows how KAC can remain below a peak level of ability when factor B is yet to be normally developed. The relevant facts are logged in Appendix B5.

In conclusion, it is clear that performance on KAC and TOMI is controlled by a number of factors. In the model, one of these factors, which we have called KS, is affected by certain kinds of use of the runway procedure that forms the basis of the KAC task. These include the Laszlo training programme and Pest, but not the Laszlo KAC test, which uses the method of Constant Stimuli. The level of KS needs to be high to support good KAC performance and the model shows how this is a limitation for the Pest, compared with the Laszlo training, only where the level of KS starts off extremely low (very clumsy children). Good TOMI performance is supported by a lower level of KS as long as the other factors, A, are well developed. These factors, KS and A, are influenced by a variety of training procedures.

The proposal that the Laszlo training programme is capable of two separate effects, one on A and the other on KS, enables us to solve the problem of accounting for Polatajko et al.'s (1995) results. These investigators also used the Laszlo procedure, but while they showed improvement on KAC, they failed to find any effects measured by TOMI. We would describe such a result as following from a particular way of administering the Laszlo programme, such that KS was improved but the other factors (A), perhaps relating partially to self-belief and motivation, were not improved (see the discussion in Sims et al., 1996b). This form of training functioned to improve KAC, but not TOMI. Figure 14 illustrates the effects of Polatajko training in terms of our model of the underlying abilities.

We have simulated our model using COGENT, an object-orientated simulation language (Cooper, Fox, Farringdon, & Shallice, 1996). The data are all consistent and the simulation came up with a number of predictions. First, the cognitive-affective programme, which has been shown empirically as having no effect on KAC performance for children with motor impairments, is predicted by our model as also having no effect on the KAC performance of normal or young subjects. Second, whereas Polatajko et al. produced no significant improvements in TOMI after training their clumsy subjects, the present model predicts that for very clumsy children (TOMI > 6.5 and no neurological damage), the Polatajko programme would bring TOMI scores from poor to medium. We do not know the exact TOMI scores of the subjects of Polatajko et al. However, the average TOMI score of their sample closely approximated those of Sims et al. (1996a, b) and therefore, the lack of TOMI improvement produced by the Polatajko training must represent the majority of their subjects, who remained at a medium TOMI level.

We have laid down a framework for portraying the key features of KAC. We provide a summary of the position we have taken in Appendix B. We still do not know the nature of the underlying factors. Following Laszlo and Bairstow (1985) we have suggested that the factor common to improvement in the TOMI and KAC tasks has to do with kinaesthetic sensitivity. We have found it necessary to postulate two further factors, which we called A and B in the model, contributing uniquely to improvement on the TOMI and KAC tasks respectively. At the moment, it is not clear how they might be characterised in terms of motor skills. The ideal would be to identify tasks that were affected by these variables but were not affected by the level of KS. We have suggested that motivation could well be a part of factor A, but have not had the data to force its inclusion in the model beyond that. It should be clear, however, that the model we have presented is a minimalist one. It cannot be simplified without losing the power to explain some of the phenomena we have presented.

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Appendix A

Appendix B

We give here a summary in tabular form of the basic data, the definitions of the populations in terms of underlying abilities and other parameters of the modelling, to allow the reader to confirm our claims.

B1: Training effects on TOMI and KAC for different populations—the data being modelled. This comes from Sims et al. (1996a, b), Polatajko et al. (1995), and the present study. A good score on TOMI is 3.5 or less, medium is between 4 and 6, and poor is above 6. A good score on KAC is 6 or less. Items marked with a superscript ^{p} are predictions.

	Population							
	Normal (and poor KAC)		Clumsy		Very clumsy		Young	
Training	TOMI	KAC	TOMI	KAC	TOMI	KAC	TOMI	KAC
Initial performance	Good	Poor	Medium	Poor	Poor	Poor	Good	Poor
Cognitive-affective	Good^{p}	Poor^{p}	Good	Poor	Medium	Poor	Good^{p}	Poor^{p}
Laszlo kinaesthetic	Good^{p}	Good^{p}	Good	Good	Medium	Good	Good^{p}	Poor^{p}
Pest kinaesthetic	Good^{p}	Good	Good	Good	Medium	Poor	Good^{p}	Poor
Polatajko kinaesthetic	Good^{p}	Good^{p}	Medium	Good	Medium^{p}	Good^{p}	Good^{p}	Poor^{p}

B2: Populations defined by underlying abilities prior to training according to the model.

Population	A	KS	B
Normal (+poor KAC)	Good	Medium	Normal
Clumsy	Medium	Medium	Normal
Very clumsy	Poor	Poor	Normal
Young	Good	Medium	Poor

B3: Training effects on underlying abilities, A, and KS according to the model.

Training	A	KS
Cognitive-affective	Poor to medium Medium to good	No effect
Laszlo kinaesthetic	Poor to medium Medium to good	Poor to good Medium to good
Pest kinaesthetic	Poor to medium Medium to good	Poor to medium Medium to good
Polatajko kinaesthetic	No effect	Poor to good Medium to good

B4: Relationships between underlying abilities (A and KS) and TOMI task.

A	KS	TOMI
Poor	Poor	Poor
	Medium	Medium
	Good	Medium
Medium	Poor	Medium
	Medium	Medium
	Good	Medium
Good	Poor	Medium
	Medium	Good
	Good	Good

B5: Relationships between underlying abilities (KS and B) and KAC task.

KS	B	KAC
Poor	Poor	Poor
	Normal	Poor
Medium	Poor	Poor
	Normal	Poor
Good	Poor	Medium
	Normal	Good