

Research report

# Do ‘clumsy’ children have visual deficits

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## Abstract

Visual processing by 10-year-old children diagnosed on the basis of standardised tests as having developmental ‘clumsiness’ syndrome, and by a control group of children without motor difficulties, was tested using three different psychophysical tasks. The tasks comprised a measure of global motion processing using a dynamic random dot kinematogram, a measure of static global pattern processing where the position of the target was randomised, and a measure of static global pattern processing in which the target position was fixed. The most striking finding was that the group of clumsy children, who were diagnosed solely on the basis of their motor difficulties, were significantly less sensitive than the control group on all three tasks of visual sensitivity. Clumsy children may have impaired visual sensitivity in both the dorsal and ventral streams in addition to their obvious problems with motor control. These results support the existence of generalised visual anomalies associated with impairments of cerebellar function.

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## 1. Introduction

The concept of developmental ‘clumsiness’ (i.e. developmental coordination disorder, developmental dyspraxia) has been discussed in the literature for at least 60 years (e.g. [9,28,34]), yet its definition remains as vague and unclear now as it did in the 1930s. Attempts at providing explanations for inadequacies in motor performance in such children have focused mainly on deficits in the cognitive processes involved in the planning and execution of movements [12].

A complementary approach, found mainly in the clinical literature, has been directed towards establishing causal links between surface manifestations of motor-impairment and underlying perceptual (dis) abilities. This literature has been dominated by work on visual-perceptual and/or visual-motor deficits [4,9,11,15–18,29]. Most of these studies have, however, been confined to identifying deficits in particular perceptual

abilities without any attempt to tease out their underlying mechanisms or the causal links between underlying neural processing and behaviour. For example, Hulme et al. [15,17] and Hulme and Lord [18] concluded simply that ‘clumsiness’, in many children, stemmed from a general difficulty in processing visual information (e.g. size consistency; visual discrimination. For a review see Henderson [14])<sup>1</sup>.

Following the studies by Hulme et al., the underlying nature of these ‘visual deficits’ was not explored further, leaving open questions as to the locus of the problem. Potential loci of the impairments include: the afferent sensory pathways (although see Mon-Williams et al. [24] for a negative finding using visual evoked potentials), the higher-level visual perceptual system, decision pro-

<sup>1</sup> Care, however, must be taken with such an interpretation because, as Hulme et al. [15] argue, it is difficult to pin-point whether the perceptual problems being demonstrated are the cause of the motor problems or if motor problems are the cause of the perceptual problems. This ‘chicken-egg’ problem remains a source of contention’.

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cesses when visual information is limited, a deficient effector system or combinations of any or all of these mechanisms.

The reasons for not testing between these hypothetical mechanisms are difficult to pinpoint. A general reticence to invoke neurological explanations is apparent in the literature [14]. Whether this was a reaction to the negative connotations of prevailing concepts like minimal brain damage (MBD) or the paucity of suitable tools for carrying out more fine-grained analyses, is difficult to ascertain.

There has, however, been resurgence in interest on both these fronts. On the one hand, Sigmundsson et al.'s [31–34] studies, showing associations between motor impairment and problems in intra and/or inter hemispheric functioning, has led to further consideration of possible neurological antecedents of developmental clumsiness. Concurrently, the magnocellular deficit hypothesis of Stein and Walsh [37], albeit in the context of research into the neurobiological basis of developmental dyslexia, has provided a general framework to explain the co-occurrence of deficits in motor and visuoperceptual skills in developmentally disabled children. What makes the latter work particularly influential is that many children with specific reading difficulties manifest clumsy behaviour characterised by, amongst other symptoms, poor balance, delayed motor milestones and weakly established lateral dominance [6,7,27,30]. Stein and Walsh [37] proposed that generalised deficits of the structure and function of a specialised set of neurons, the magnocells, could account for the co-occurrence of deficits in the detection of transient sensory stimuli in the visual, motor and auditory domains in dyslexia. In the context of children's motor impairments, previous findings make two contrasting predictions as to the locus of their 'clumsiness', first, the visual-perceptual deficits often associated with developmental clumsiness might be a consequence of impaired transmission of visual information, particularly within the extrastriate dorsal stream that receives a large input from the visual magnocellular pathway. Such deficits would be expected to affect visual operations that require the coding of information about the spatial positions of objects relative to the observer. Alternatively, the impairments might be attributable to modular deficits in motor functions irrespective of the visuoperceptual system. (Note that these motor deficits might still be attributable to a magnocellular deficit in the non-visual vestibular and motor systems (see, Stein and Walsh [37])).

It is well known that visual information is processed in parallel by neural pathways that remain largely segregated between the retina and input layers of visual cortex. The visual streams project mainly to separate areas in extrastriate cortex [22,23], although the intermixing between the inputs of the temporally projecting

'ventral' stream and the 'dorsal' stream projecting to structures in the parietal lobe is substantial [22]. The areas to which these streams project mediate very different types of visual function. Dorsal stream structures generally convey information about the spatial relations between objects and about their motion, whereas ventral stream structures are involved more in providing information about the surface properties of objects such as their shape and colour [22]. For example, within the primate dorsal stream, cells in the middle temporal visual area (V5/MT) are extremely sensitive to global coherent motion [26], but cells within area V4 in the ventral stream are sensitive more to the global coherence of complex visual patterns [8]. In humans, psychophysical detection thresholds for dynamic motion and for static form stimuli have been found to be statistically independent both in clinical groups [1,10,36] and normal, control populations [2,10]. Such experimental evidence supports the idea that these stimuli are tapping into the sensitivity of different cortical visual pathways [2].

Visual deficits for global coherent motion, but not global coherent form stimuli in developmental disabilities such as Williams syndrome [1], autism [36] and developmental dyslexia [10] have been argued to result from the selectively impaired sensitivity of cells within the magnocellular retinocortical pathway and the extrastriate, dorsal stream areas to which a large proportion of magnocells project (see Stein and Walsh [37] for review). In a recent study, Hansen et al. [10] replicated previous results [3,40], demonstrating that a group of dyslexic adults were significantly less sensitive than controls for detecting global motion in random dot kinematograms. However, the same subject group was equally sensitive as controls on two measures of coherent form detection.

In this study, we applied the same measures of global form and motion sensitivity as were employed in the Hansen et al. study to test whether impaired visual function is characteristic of children with motor impairments. Secondly, our visual tasks, which tap the sensitivity of different underlying visual processing streams, will enable inferences to be drawn as to whether any deficit found provides evidence for a deficit selective to either the dorsal or ventral visual stream.

## 2. Materials and methods

### 2.1. Subject selection

Fifty-four school children aged 10–11 years (range 10 years, 2 months to 11 years, 1 month) were evaluated on the Movement ABC test [13] of motor competence.

All of the children at the school, who were within the appropriate age range were tested; they were, therefore,

not preselected in anyway. The entire sample attended normal, mainstream classrooms and no child had any reported history of learning difficulties or any behavioural or neurological problem that would qualify as exclusionary criteria for this study.

The 13 children with the highest scores (a high score indicates motor problems) were designated the ‘clumsy’ group, while the 13 children with the lowest scores constituted the control group (Table 1). We use the term ‘clumsy’ rather than developmental coordination disorder because the children were categorised purely on their performance on a test battery of motor skill rather than a more detailed neuropsychological assessment. The mean chronological ages for the clumsy group was 10.6 (S.D. 0.2) and for the control group 10.5 (S.D. 0.3). Each group comprised seven females and six males, who all demonstrated right hand preference (as determined by hand usage when writing their name and in the ‘flower trail’ and ‘throwing bean bag’ tasks of the measures of cerebellar function (MABC) test, see below). Despite the overall differences between groups on the MABC, the groups did not significantly differ ( $P > 0.05$ ) in their performance on the following MABC subtests: threading nuts, flower trail, and ball balance. This suggests that the group of motor impaired children was not generally impaired on tasks of psychometric or psychomotor skill.

## 2.2. Movement ABC

The Movement ABC test [13] is an extended version of the well known test of motor impairment (TOMI). It was designed to better identify children with motor coordination problems.

Table 1  
Gender (M/F), chronological age (CA), and ABC scores for the clumsy and control groups

Clumsy group			Control group		
Subject	CA	ABC	Subject	CA	ABC
1 (M)	10.7	23.0	14 (M)	10.9	0
2 (M)	10.5	19.5	15 (M)	10.4	0
3 (F)	10.8	17.5	16 (F)	10.3	0.5
4 (F)	10.8	17	17 (M)	10.3	0.5
5 (F)	10.5	15.5	18 (M)	10.3	1
6 (M)	10.3	15.5	19 (M)	10.2	1
7 (F)	10.5	14.5	20 (F)	11.1	1
8 (M)	11.1	14.5	21 (F)	10.5	1.5
9 (M)	10.3	11.0	22 (F)	10.2	1.5
10 (F)	10.6	10.5	23 (M)	10.8	2.5
11 (F)	10.2	10.5	24 (F)	10.7	2.5
12 (F)	10.9	10	25 (F)	10.7	2.5
13 (M)	10.5	10	26 (F)	10.8	3
Mean	10.6	14.5		10.5	1.3
S.D.	0.2	4.1		0.3	1.0

It is a formal standardised test that provides both a quantitative and a qualitative evaluation of the child’s motor competence in a wide range of tasks associated with daily life. Normative data on the MABC ranges to include children aged from 4 to 12 years. Children are scored on eight sub-tests: shifting pegs by rows, threading nuts on bolt, flower trail, two hand catch, throwing bean bag into box, one-board balance, hopping in squares, and ball balance.

On the basis of the test norms it is possible to establish whether a child has a normal motor competence (compared with 85% of children of the same age), borderline performance (85–95%) or, belongs to the 5% with a deviant performance (95–100%) relative to children of the same age. In the age group, we tested an ABC score of ten would place the child at the 15%ile and a score greater than 13.5 at the 5%ile.

## 2.3. Psychophysical paradigms

The visual processing tasks comprised, (a) a measure of global motion processing using a dynamic random dot kinematogram (MOT); (b) a measure of static global pattern processing where the position of the target was randomised (FORM\_R) and; (c) a measure of static global pattern processing in which the target position was fixed (FORM\_F). Each of these measures required the detection of a global visual signal embedded in noise. This global signal was defined in terms of its coherence, defined as the ratio of stimulus elements in the target signal to the remaining noise elements (see Fig. 1). Coherence was varied systematically to the psychophysical detection threshold in all three tasks using the same

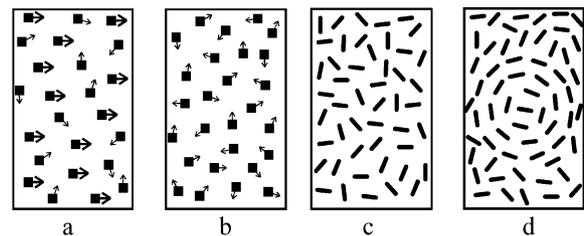


Fig. 1. Schematic diagrams of the coherent motion (panels a, b) and coherent form (panels c, d) paradigms. For the coherent motion stimuli, the arrows represent the motion vector of each dot in the panel. Panel a depicts 50% coherence; half the dots are moving together (in this case reversing left and right), whereas the rest of the dots are moving in random directions. Panel b depicts the random motion in the non-target RDK patch. Each dot moves in a random direction so the average coherence value is close to 0%. Panels c and d depict the coherent form task. In this measure subjects detect a circle which is comprised of coherently oriented line segments. Panel d shows the patch that contains the coherent form. The outline depicts the region within the panel that contained the coherent target. Threshold is defined as the percent coherent signal averaged over a number of staircase reversals for each stimulus type. See text for details. (Stimuli are not drawn to scale).

adaptive staircase procedure, implemented with custom software written for PCs.

The RDK motion stimuli were similar to those used previously [10]. Two patches of 300 high luminance white dots (1 pixel) were presented on the black background of a computer monitor. One patch contained a variable percentage of target dots that moved coherently in the same direction (either leftwards or rightwards) over successive screen refreshes and reversed direction every 1002 ms. The remaining noise dots moved with the same speed but with a randomly changing direction between screen refreshes in a Brownian manner. The second patch contained only noise dots. The patch containing the coherent signal was selected at random by the stimulus program.

In order to eliminate the possibility of following the trajectory of a single dot, each element in the display had a fixed lifetime of four animation frames (200 ms) after which it would disappear before being regenerated at a random place within the same stimulus patch. Percentage of coherent motion was corrected for this finite dot lifetime. When all the dots in the target patch were moving coherently, and dots had a lifetime of four frames, this was equivalent to an infinite dot lifetime threshold of 75% coherence. The percentage of target dots (angular velocity =  $7.0^\circ/\text{s}$ ) within a given software animation frame (50.1 ms) was varied to the detection threshold by a spatial, two-alternative, forced-choice staircase procedure [19] starting from an initial value of 75% coherence that can be easily seen by all the participants. For each correct response the coherence of the stimuli was decreased by 1 dB (a factor of 1.122) and for each incorrect response the modulation depth was increased by 3 dB (a factor of 1.412).

Binocular viewing of the patches was conducted in a darkened environment. Children wore their normal optical correction, if necessary. At a viewing distance of 57 cm, each patch subtended  $10 \times 14^\circ$  of visual angle separated horizontally by  $5^\circ$ . The participants were instructed to inspect each stimulus patch during the 4.0 s stimulus interval and to identify the patch that contained the coherent motion by making a verbal response (e.g. 'one' or 'two'). This response corresponded to labels that were placed above each patch on the frame of the computer screen. Responses were then entered into the computer by the experimenter using the keyboard, which initiated the next trial.

Threshold was defined as the smallest proportion of coherently moving target dots required for detecting coherent motion. This was determined by taking the geometric average of the last eight of ten reversal points within a given staircase. Only accuracy data was recorded; the subjects were under no time constraints other than the fixed duration of the stimulus. Each staircase procedure was repeated twice; the arithmetic mean of these two estimates was defined as the subject's

detection threshold. Each threshold estimate took approximately 5 min to complete.

The two measures of global form coherence were of the same application and design to the coherent motion task. Both required the detection of a coherent form signal, defined by line segments that were oriented in tangent to an imaginary concentric circle of  $8^\circ$  diameter. The coherent form target was embedded in a field of 'noise', comprised of line segments that were oriented randomly. Only one patch contained the coherent target, the second patch contained only noise elements (see Fig. 1). Each of the patches contained 600 high luminance line segments, each  $0.4^\circ$  in length. The size of the patches and luminance of the line segments were matched to the values used in the motion task. The percentage of coherently oriented line segments was determined algorithmically and varied to the subject's detection threshold using the same adaptive staircase procedure as the coherent motion test, starting from an easily detected starting value of 75% coherence. Detection threshold was defined as the proportion of coherently oriented line segments necessary to detect the circle target. The order of all the visual tests was counter-balanced across subjects to control for the effects of practice and fatigue.

In the form-fixed task (FORM\_F), the target could only appear in the center of either the left or right patch. In the form-randomised task (FORM\_R), the position of target pattern within either patch was assigned randomly with the constraint that the entire target circle remained within the patch. Detection of the target in the FORM\_R task thus required visual search over both panels, rather than monitoring a limited area within either patch. These increased demands required that the stimulus duration was unlimited compared with the 4.0 s allocated to each trial of the motion task. This was unlikely to have had any significant effect on the results reported here, however, since motion detection performance asymptotes at stimulus durations around 1 s [38]. It should be noted that coherent motion detection is limited more by the dot lifetime than by the overall duration of the display [35] suggesting dependence on a time-independent parallel process, rather than a time-dependent serial process [5].

### 3. Results

#### 3.1. Group comparisons

The data, with respect to group comparisons, was analysed in two ways, (a) by taking the average threshold of the two threshold estimates for a task and (b) by taking the child's best threshold estimate from either the first or second trial. The averaged threshold data for each of the groups is shown in Fig. 2. Although reports

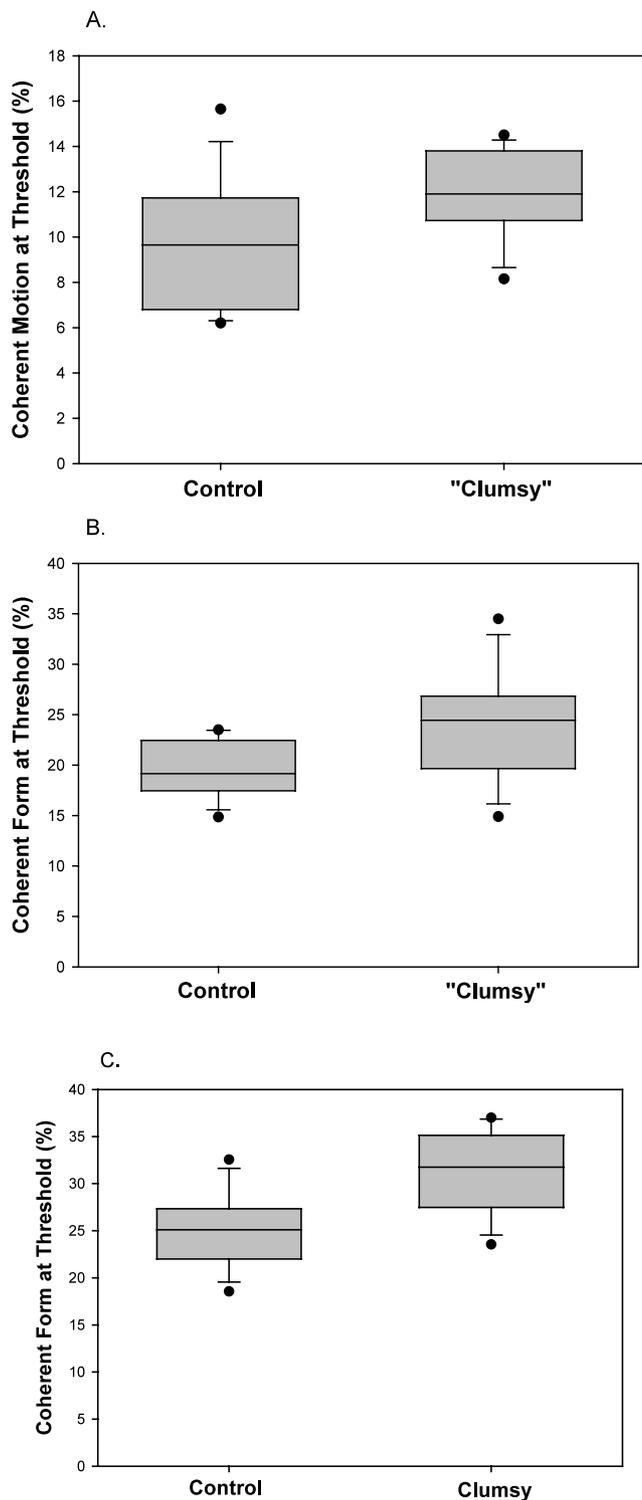


Fig. 2. Box plots depicting the control ( $n = 13$ ) and 'clumsy' ( $n = 13$ ) children's performance on the psychophysical tests of visual performance. (A) Coherent Motion ( $U = 41.0$ ,  $P = 0.026$ ). (B) Coherent Form fixed ( $U = 34.0$ ,  $P = 0.009$ ). (C) Coherent Form randomized ( $U = 27.0$ ,  $P = 0.002$ ). Horizontal lines within boxes represent the group medians. Box edges define the first and third quartiles, whiskers define the 10 and 90%iles, solid circles define threshold values that fall outside the 95% confidence interval for these data.

of subgroups of clumsy children exist in the literature [21], our relatively small sample size did not afford us the opportunity to compare these putative subgroups on the sensory tasks. Conservative, non-parametric group comparisons (Mann–Whitney  $U$ ) showed that the group of clumsy children had significantly higher thresholds for all three of the visual measures (coherent motion ( $U = 41.0$ ,  $P = 0.026$ ), coherent form fixed ( $U = 34.0$ ,  $P = 0.009$ ), coherent form randomised ( $U = 27.0$ ,  $P = 0.002$ )). This effect was the same if threshold was defined as a child's most sensitive threshold estimate, rather than the arithmetic average of two estimates (coherent motion ( $U = 40.0$ ,  $P = 0.022$ ), coherent form fixed ( $U = 38.5$ ,  $P = 0.016$ ), coherent Form randomised ( $U = 25.0$ ,  $P = 0.0012$ )).

### 3.2. Comparisons between visual tests

Thresholds for the form-randomised measure were nearly universally higher than those for the test where the form target was fixed (Wilcoxon  $z = 4.026$ ,  $P < 0.001$ ). Only two of 26 subjects had lower thresholds when the position of the form target was randomised. This demonstrates the greater task difficulty when visual search is required and suggests that, unlike motion coherence, search for visual form is a serial rather than parallel process. However, consistent with the hypothesis that sensitivity on both form coherence tasks is mediated by the same visual mechanisms (i.e. such as V4 [8]), the average thresholds for the two measures of global form sensitivity were highly correlated across the entire group of subjects (Spearman  $r$  ( $r_s$ ) = 0.57). However, consistent with other results that have demonstrated the statistical independence of form and motion processing (e.g. [2,10]), thresholds for the form test were poorly correlated with motion coherence thresholds ( $r_s = 0.2$ ), especially for the form task with a fixed target position. The stronger correlation between thresholds on the measures of coherent motion and coherent form with position uncertainty were relatively stronger ( $r_s = 0.38$ ). This result may reflect the greater involvement of the dorsal stream structures that are sensitive to visual motion in tasks requiring visual search (e.g. [23,38]).

### 3.3. Correlations between visual tasks and measures of cerebellar function (MABC)

Significant correlations were found between scores on the MABC and sensitivity on all three visual tasks, demonstrating that poor motor skills are associated with lowered visual sensitivity (sensitivity = 1/threshold). Motion ( $r_s = 0.39$ ,  $P < 0.05$ ), form static ( $r = 0.46$ ,  $P < 0.02$ ), form random ( $r_s = 0.64$ ,  $P < 0.001$ ).

#### 4. Discussion

The purpose of this study was to determine whether visual processing deficits, shown to be characteristic of some categories of dyslexic children are also characteristic of clumsy children. The most striking finding from the study was that developmental clumsiness is associated with visual deficits for the detection of both global visual motion and global visual form (i.e. this group of subjects with motor impairments were less sensitive than a control group on measures of both putative dorsal and ventral stream functions). These general visual deficits are not consistent with the locus of the visual deficit being restricted to either the visual magnocellular pathway or the visual dorsal stream as is suggested in other developmental disorders [1,10,34]. Our data are also not consistent with the evidence for a specific magnocellular visual deficit in cerebellar dysfunction as suggested by Nawrot and Rizzo [25]. Our data are more consistent with the more generalised pattern of visual deficits identified by Thier et al. [41] in patients who have cerebellar lesions. They showed that cerebellar lesions were associated with visual deficits both for measures of dynamic (including detection of coherent motion) and static (such as judgements about spatial position) visual function. This suggests that the influence of the cerebellum in visual tasks is not limited to measures in which stimulus timing and change are central features of the stimuli.

The more generalised visual anomalies that are apparent associated with developmental clumsiness are not consistent with the hypothesis of a deficit selective to either timing functions or to the magnocellular pathway. Although sensitivity to dynamic stimulus was lowered in the children with motor impairments, the largest statistical group difference was found on the form coherence task with a fixed target position. This is the least difficult of the two form coherence measures. Nearly all of the participants in both groups were more sensitive on this task because the form target appears in only one of two possible positions (i.e. in the centre of either the left or right panel).

It was not possible to carry out intelligence tests on the children so we can not rule out the possibility that other cognitive differences between the groups of children affected the pattern of results we obtained. However, all of the children in both groups attended normal classrooms and no child had any reported history of learning or reading disability. Given the high comorbidity between learning difficulties and deficits in motor skills, however, (e.g. [6,7]) leaves open the possibility that some of the children had undiagnosed dyslexia or other impairments of learning. This is clearly an area where future study is warranted. Despite this uncontrolled factor, the pattern of results we obtained is not likely to be attributable to a general

difference in learning effects between the two groups. When the performance of each of the two groups of children were compared using paired analyses across the two trials of each test type, no significant differences were found (Mann–Whitney  $U$ : motion = 72.0,  $P$  = 0.54; Form\_F = 60.0,  $P$  = 0.22; Form\_R = 76.0,  $P$  = 0.69). This shows that there were no systematic differences between groups in their ability to improve across the trials of the psychophysical measures. This lack of a learning effect suggests that the differences found between groups resulted from true differences in the sensitivity to the visual stimuli employed, rather than differences in the groups' overall ability to attend to and complete the tasks.

It is also unlikely that the differences between the two groups resulted from a general difference in working memory or information processing speed between groups. Both the target and non-target patches were presented simultaneously (i.e. our paradigms had no ISI) and we used a long stimulus duration (4 s) to the potential confounding influence of memory and information processing speed on our visual tests.

Although we did not measure eye movements, and might expect on the basis of previous studies for the clumsy children to have poorer eye movement control than the control group controls (e.g. [20]), it is unlikely that eye movement differences alone could explain the pattern of result reported here. Differences in eye movements could result in impaired visual search performance, which could explain our group differences on the form task with a randomised target position. However, for both the form detection tasks the duration of the stimulus was unlimited and terminated only by a subject's response. Effects mediated by differences in eye movement control between groups would be minimised by these long stimulus durations. Similarly, the difference in sensitivity between groups found on the form task with a fixed target position, can not easily be explained by differences in eye movement control because this task, can be performed with very few eye movements.

Processing in MT and adjacent motion sensitive areas can be modulated by visual attention [42]. Similarly the ability to direct visual attention may depend upon the sensitivity of motion sensitive areas [39]. Lower thresholds for both form and motion suggest that both serial and parallel search processes are likely to be affected.

Braddick et al. [2] have recently compared the functional activation's elicited by detecting global form and motion coherence using fMRI and a stimulus set largely identical to the ones we have applied using psychophysical methods in this study. In support of the psychophysical findings that demonstrated little correlation between the form and motion measures, they showed that the functional activation's elicited by form and motion detection did not overlap. However,

in contrast to the expected dissociation of activation into dorsal and ventral streams (for the motion and form coherence measures, respectively), they showed that the foci of activation ran in parallel from occipital to both temporal and parietal areas. This suggested a more tightly integrated network of visual areas to support object localisation and recognition. Perhaps it is the deficits in each of these domains that leads to a difficulty in utilising both form and position information toward the on-line guidance of movement in clumsy children.

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