Perceptual Deficits in Clumsy Children: Inter- and Intra-modal Matching Approach—A Window into Clumsy Behavior

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ABSTRACT

This article will focus on the underlying perceptual deficits that might lead to inadequacies in motor performance in children. Two lines of enquiry have dominated the literature: visual-perceptual deficit and/or visual-motor deficits and proprioceptive deficits. The theoretical and methodological shortcomings in these approaches are discussed. Then attention is primarily directed toward the concept of inter- and intra-modal matching (sensory integration), particularly with respect to vision and proprioception, an ability deemed to underlie many real-life motor skills. Such an approach allows parallels to be drawn between behavioral manifestations of motor impairment and potential underlying neurological information-processing disorders, particularly as these relate to hemispheric competence.

KEYWORDS

perceptual information, inter-/intra-modal, intra-/inter-hemispheric processing; lateralization

INTRODUCTION

Definitions and Etiology

The possibility that the neural factor in many cases of motor impairment may stem from circumstances other than those of brain damage has remained relatively unexplored. As a result of this situation, a child with obvious difficulties in skill learning may not be recognized as being impaired because of the failure of any test of brain damage to identify the cause (Morris & Whiting, 1971, p. 155).

Nearly 30 years after this statement was made, a review of the literature will confirm that attempts to explore its implications have been few and far between. Where this has happened, researchers have been wary of elaborating upon, or delving too deeply into, possible nomological networks. This paper is a step towards redressing that imbalance, its departure point being that neuropsychological factors may figure more prominently in explanations of motor impairment than has been appreciated.

Some reasons for this apparent neglect can be attributed to the fact that the concept of motor impairment is both diffuse and ill defined. Attempts to refine definitions to distinguish the phenomenon from extant disease entities may, it is suggested here, have resulted in throwing out the baby with the bath water. Motor impairment is a concept that has been discussed in the literature for at least 75 years (for example, Orton, 1937; Walton et al., 1962; Morris & Whiting, 1971; Gubbay, 1975;

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Gordon & McKinley, 1980; Henderson & Hall, 1982; Sigmundsson & Whiting, 2002) at which time the Russian Oseretsky (1923) from the Psychoneurological Clinic in Moscow, rather significantly, was developing tests designed to aid in broad diagnoses of neurological and motor deficiency. As a behavioral phenomenon, however, motor impairment must have been observed since time immemorial, much to the frustration of both parents and members of the medical profession confronted by children exhibiting the syndrome.

Prevalence and Characteristics

Most recent definitions of motor impairment invoke the concept of *norms* although it would generally be accepted that they are difficult both to quantify and to establish, particularly in the absence of any clear consensus about what is *normal* development. Despite these difficulties, various estimates of the prevalence of the syndrome have been put forward on the basis of the results of a number of different standardized tests. These estimates have ranged from 5% to 10% when limited to children in the age range 5 to 12 years (see for example, Brenner et al., 1967; Gubbay, 1975; Henderson & Hall, 1982; Mæland, 1992; American Psychological Association, 1994). Mæland's (1992; Søvik & Mæland, 1986) 6% estimate, based on the use of standardized tests, of the number of school-age children in Norway manifesting the motor impairment syndrome is very similar to estimates made in other countries (Brenner et al., 1967; Gubbay, 1975; Henderson & Hall, 1982) when similar criteria have been invoked. Most prevalence studies report a much higher incidence of motor impairment in boys than in girls (Gubbay, 1978; Henderson & Hall, 1982; Keogh et al., 1979; Mæland, 1992).

The importance of recognizing the syndrome and not dismissing it 'as within the norm' is that difficulties experienced by the motor-impaired

child can be expected to have a knock-on effect in a wide range of skills—motor, social, linguistic, and so on. Note, for example, that 2% to 10% of children of similar age groups have been reported to have a variety of language problems, manifested in speech, reading and writing (Rutter, 1978; Stevenson, 1984; Gaddes, 1985; Stein, 1994; American Psychological Association, 1994). Perhaps more noteworthy in the present context is a reported overlap of between 40% and 70% in the number of children exhibiting both motor and language impairments (Paul et al., 1983; Wolff et al., 1995; Rintala et al., 1998; Nickisch, 1998; Estil et al., 2003). The suggestion that this overlap is unlikely to be fortuitous led Estil and Whiting (2002) to explore whether, when language and motor impairments occur together, the relation is *direct* or *indirect*. The notion of a *direct* relation would imply that both kinds of impairment are simply different manifestations of one underlying substrate, for example, a poorly developed or dysfunctional neurological system. An *indirect* relation, in contrast, would imply that there is one primary problem—either motor or language—and that the secondary related problem—either language or motor—arises as a consequence of social constraints to which the primary problem gives rise.

Given such a broad-based syndrome it is not surprising that there should be universal agreement that motor-impaired children do not constitute a homogeneous group (Søvik & Mæland, 1986; Sigmundsson et al., 1997a) although the tendency in the literature has been to do just that. That this may be an unfortunate omission is attested to by Dodd et al., (1989) albeit in the context of language impairment—who report that the different patterns of performance of their groups on different experimental tasks supports the notion that subgroups are relatively distinct and that their different surface production errors reflect different underlying deficits. If the implications of this

statement are not accepted, then the methods of intervention provided for non-specified groups of motor impaired children can be only of a very general kind. More specific forms of intervention must, therefore, await the establishment of acceptable criteria for delineating sub-groups and more in-depth knowledge of the reasons underlying the impairment.

PERCEPTUAL DEFICITS IN MOTOR-IMPAIRED CHILDREN

One attempt to go beyond the level of description with respect to putative factors underlying motor impairment has been that of ability testing. Following on the distinction made by Fleishman (1966) between skill and ability, there has been a noticeable attempt on the part of both experimental and developmental psychologists to explore the nature of underlying perceptual deficits that might lead to inadequacies in motor, language and social performance in children.

Two particular perceptual modes, perhaps not surprisingly, have attracted most attention, namely, the visual (Gubbay et al., 1965; Dare & Gordon, 1970; Henderson & Hall, 1982; Hulme et al., 1982a; Hulme, et al., 1982b; Hulme et al., 1984; Hulme & Lord, 1986; Powell & Bishop, 1992) and the proprioceptive¹ (Bairstow & Laszlo, 1981; Laszlo & Bairstow, 1985; Laszlo et al., 1988; Smyth, 1991; 1994).

Theoretical problems

Although these explorations have provided much useful information and triggered a number of new research paradigms, the theoretical and

methodological frameworks in which they have been couched have limited their impact. As a consequence, there has been little consensus as to the causal agencies underlying such putative deficiencies in the form, for example, of neurological lag or impairment (for example, Hulme et al., 1982a,b; 1984; Hulme & Lord, 1986; Laszlo & Bairstow, 1985; Laszlo et al., 1988; Laszlo, 1990; Laszlo & Sainsbury, 1993; Smyth, 1991; 1994).

With respect to visual-perceptual deficits, Hulme et al., (1982a; 1984), using a task of line-length matching within or between the modalities of vision and proprioception, and Hulme and Lord (1986) concluded that for many children their 'clumsiness' stems from a difficulty in processing visual information (for example, size consistency; visual discrimination). Unfortunately, the authors did not explore the nature of the putative 'visual deficits'. Did the problem reside in the sense organs, the visual perceptual system, decision-making based on limited visual information, a deficient effector system or combinations of all these?

Other researchers have focused on deficiencies in proprioceptive sensitivity and its role in relation to impaired perceptuo-motor performance (Laszlo & Bairstow, 1985; Laszlo et al., 1988). These investigators used a task that required children to discriminate (proprioceptively without vision) the heights of two inclined runways. Interesting as their findings are, they take no account of a possible lateralization effect, which, as will be suggested below, may be an important factor in relation to causality. An extension to their explanatory framework on the basis of, for example, literature in which neurological lesion/disconnection has been linked to apraxia (see for a review Heilman & Rothi, 1993) might have raised a number of important research questions.

¹ Proprioception: those receptor mechanisms, most noticeably in the joints, muscles and tendons, that signal information about the posture and movements of the body as a whole (Sherrington, 1906)

Methodological and analytical problems

Despite this limitation, the visual perceptual deficits hypothesis of Hulme and his colleagues (Hulme et al., 1982a,b; 1984; Hulme & Lord, 1986), justified only by correlational studies, is less well supported by experimental findings than the proprioceptive deficits hypothesis put forward by Laszlo and her colleagues (Laszlo & Bairstow, 1985; Laszlo et al., 1988). Be that as it may, Doyle et al. (1986) also questioned their use of the constant stimuli methodology, particularly the failure to take cognizance of the constraints associated with this procedure, namely, the values of the stimuli relative to the threshold and the number of observations made at each value (Sigmundsson et al., 2000). Furthermore, Elliott et al. (1988) and Sugden and Wann (1988) presented data inconsistent with the findings of Hulme and coworkers.

Despite these critical standpoints, this approach and attempts to determine underlying causal factors proved sufficiently challenging to justify exploring the concept of perceptual deficit further, albeit from a different perspective. It has long been recognized that to carry out coordinative actions in an affective way, close integration of information stemming from both inter and intra sensory systems is necessary:

In most cases of manual behavior, both vision and proprioception will affect the outcomes of manual movements. In fact, if such movements are to be smooth and well coordinated, it is of crucial importance that visual and proprioceptive means of controlling them are in correspondence. This implies that the parameters of space defined by each of these systems are in fine agreement. If both hands are involved in an act, it is also important that the proprioceptive space defined by one limb is in correspondence with the proprioceptive space defined by the other limb (Hofsten & Rösblad, p.806).

Lee et al., (1990) supported this standpoint, arguing that this linking of information (inter- and

intra-modal) is crucial to the development and to the maintenance of motor competence. That inter (visual space-proprioceptive space) and intra (proprioceptive space-proprioceptive space) modal matching might provide insight into the nature of the motor impairment syndrome was proposed, initially, in an investigation (unpublished) carried out by Jongmans (1989) and cited in Henderson (1993). Using a paradigm that Hofsten and Rösblad (1988) originally used with normal children, Jongmans investigated the performance of children exhibiting clumsy behavior required to perform a manual matching task to locate a target in which the availability of vision and proprioception were systematically manipulated. Matching the located target was always carried out without vision. Given that the movements required were minimal, success on the task depended to a large extent on the ability to match visual/proprioceptive and proprioceptive information in locating targets. The results showed that while the target remained visible, the motor-impaired group performed as accurately as their control peers. Moreover, the addition of proprioceptive information in locating the target did not improve the performance of either group. When only proprioceptive information about target location was available, however, both groups were less accurate, but the decrease for the motor-impaired group was much more striking (Henderson, 1993). This kind of finding led Sigmundsson and co-workers, beginning in 1997, to instigate a series of studies on motor impaired children in which the methodology of inter-modal and intra-modal sensory matching was used. The idea was to explore putative neurological explanations of motor impairment more intensively.

PUTATIVE NEUROLOGICAL DISORDER IN HECP CHILDREN

In the following studies, cognizant of the problems involved if distinctions are not made

between sub-groups of children manifesting the motor impairment syndrome, more clearly defined sub-groups were selected, namely, those exhibiting hand-eye co-ordination problems (HECP). For this purpose the Movement ABC test (Henderson & Sugden, 1992) was used, the children being ranked on the basis of their summed scores on the five hand-eye co-ordination subtests—throwing a bean bag, following a flower trail, playing bounce and catch, placing pegs, threading a lace. The HECP sample used in Sigmundsson et al. (1997a, b) and Sigmundsson (1999) had hand-eye co-ordination sub test scores of 11.3 on the ABC test and the sample used in Sigmundsson et al., (1999) had scores of 11.62. Test procedures developed in the authors' laboratory for this purpose, in contrast to those that focus only on surface behavior, have been directed towards those sensory integration abilities deemed to underlie the way in which these children carry out a range of everyday motor tasks (Laszlo & Bairstow, 1985; Hofsten & Rösblad, 1988; Rösblad & Hofsten, 1992; Lee et al., 1990; 1997). In this way it has been possible to draw parallels between behavioral manifestations of 'clumsiness' and possible underlying neurological information-processing disorders, particularly as these relate to hemispheric competence. This research was facilitated by the elaboration of an earlier developed testing instrument for sensory integration (Sandström, 1953; Sandström & Lundberg, 1956; Hofsten & Rösblad, 1988).

Sensory integration tests

1. *Manual matching task: 'Inter-and intra-modal matching'.* Basically, the testing procedures require the sensory matching of targets located visually (seen target), with the hand (felt target) or in combination (felt and seen). Matching of the position of located targets is normally carried out without vision—an exception being the Sigmundsson (1999) study.

Studies carried out using sensory matching testing procedures (see Table 1) (Sigmundsson et al., 1997a,b; Sigmundsson, 1999) produced evidence of significant differences in inter- and intra-modal matching between right-handed HECP and normal children (age ranges 5 to 8 years) when combined scores for both hands were analyzed. The analysis of scores achieved with the right and left hand separately, however, demonstrated that the differences between the HECP and the control children could, in the main, be attributed to lowered performances when the left hand (non-preferred hand) was used for matching the located target position. Further, intra-group analyses of the HECP children produced evidence of significant asymmetrical differences in intra-modal matching when the children were required to locate targets with the right hand and match the located target's position with the left hand compared to the condition in which they were required to locate with the left hand and match with the right hand. The performance in the latter condition was superior.

When the HECP children were required to use the left hand (right hemisphere mediation) to match the located target, their respective error scores under the visual as compared to the proprioceptive condition were 20 mm and 36 mm. The control children in this respect had 14 mm and 24 mm in error scores (see Fig. 1). When using the right hand (left hemisphere mediation) to match the located targets, however, the respective error scores of the HECP children under the visual, as compared to the proprioceptive condition, were 22 mm and 25 mm. The error scores of the control children were 14 mm and 22 mm. These findings strongly suggest that the HECP children have input/planning problems when they are made dependent upon proprioceptive information picked up via the right hand (Sigmundsson et al., 1999a). The findings also clearly indicate the problem that the HECP children have compared with the control

TABLE 1

Overview of studies on inter-and intra-modal matching by 7- and 8-year old children diagnosed as having hand-eye co-ordination problems (HECP) and by a control group of children without such problems.

STUDY	INPUT	OUTPUT	P *	POSSIBLE EXPLANATIONS OF THE DIFFERENCES
Sigmundsson et al.1997a,b	Vision	right hand	s (mean AE)	visual-perceptual and/or visual-
	Vision	left hand	s (mean AE)	motor deficits
Sigmundsson et al.1997a,b	Vision/right hand	left hand	s (mean AE)	visual-perceptual and/or visual-
				motor deficits, problem which modality to rely on
Sigmundsson et al.1997a,b	Vision/left hand	right hand	ns	
Sigmundsson et al.1997a,b	Right hand	left hand	s (mean AE)	right hemisphere insufficiency with
Sigmundsson, 1999	Right hand	vision/left hand	s (mean AE)	or without dysfunctional corpus
Sigmundsson et al.1999	Right foot	left hand	s (mean AE)	callosum
Sigmundsson et al.1997a,b	Left hand	right hand	ns	
Sigmundsson, 1999	Left hand	vision/right hand	ns	
Sigmundsson et al.1999	Left foot	right hand	s (mean VE)	right hemisphere insufficiency with
				or without dysfunctional corpus
				callosum
Sigmundsson et al.1999	Left foot	left hand	s (mean VE)	right hemisphere insufficiency

*significant (s) differences between the HECP** and the control group of children on the mean absolute error (AE) score and mean variable error (VE) score (within subject variability).

**In order to ensure that the findings were not the consequence of a particular selection of subjects, two different samples of HECP and controls were selected.

Fig. 1: Mean distance target-pin (t-p; millimetres) scores for the two conditions of the experiment for hand-eye co-ordination problem (HECP) and control groups matching with the right hand (rh) and the left hand (lh) (V vision only; P proprioceptive only)

Legend: ■ HECP □ Control

children in the inter-modal condition, namely, when the targets are located under visual control. Sigmundsson et al. (2002) followed up this possible 'visual deficit' and found that clumsy children have a problem regarding visual processing, namely, they can have impaired visual sensitivity in both the dorsal and ventral streams.

2. *HEMI-task: 'Toe-hand' matching.* This task, in principle, provides the possibility to distinguish between intra- and inter-hemispheric competences in 'on-line' (namely, no proprioceptive/tactile memory trace (off-line) is involved) target location-matching. Using the foot rather than the hand to locate targets allows the possibility of examining performance when the information processing involved is *within* hemispheres as well as *between* hemispheres (a possibility that is not afforded when the hand is used for location and the other hand for matching) (Sigmundsson et al., 1999a). Such a procedure, it was thought, might provide a window into information processing in the brain. The findings from a study (Sigmundsson et al., 1999a) carried out on a different group of 7-year-old right-handed HECP children showed that they did manifest inferior performance to the control children in 3 of 4 conditions where the right hemisphere was involved and/or information had to be transported across the corpus callosum (Table 1).

The left hand-right hemisphere problems shown (Table 1) are clearly not a feature of normal development and may therefore indicate a putative neurological abnormality. Invoking the hypothesis of Sperry (1974), Bogen (1990; 1993), and Waal et al. (2000) about hemispheric specialization, these findings could be accounted for by right hemispheric insufficiency (lesion/disconnection) (Geschwind, 1975; Faglioni & Basso, 1985; Heilman & Rothi, 1993) with or without a dysfunctional corpus callosum which, in turn, might be attributable to slow maturation (Yakolev & Lecours, 1967; Trevarthen, 1974; Galin et al., 1977; O'Leary, 1980; Quinn & Geffen, 1986) or an

interruption of transcallosal interhemispheric communication—the so-called 'callosal concept' of Bogen (1993). If these findings and theoretical interpretation should prove to be generalizable, then it would be expected that left-handed HECP children, in contrast, would be likely to have particular problems when using their right hand to match the position of the located targets. This was exactly what Sigmundsson & Whiting (2002) found in a further study, thus, providing further support and extending the suggestion that the problems of HECP children, when compared with control peers, manifest themselves more clearly when they are required to use their nonpreferred hand.

The findings from Sigmundson (1999), in which the real-life skills of 'threading nuts onto a bolt' and 'threading beads' were the paradigm tasks, support these interpretations. These and similar tests have long been used in the literature and, more recently, have been developed by Henderson and Sugden (1992) and form part of their well-known Movement ABC test battery. In the Sigmundson study the focus was on 8-year-old right-handed HECP children and a control group.

Visual-motor task

'Threading beads'-task. 'Threading beads' is a bimanual task (the hands coordinate in performing separate aspects of the same task) demanding interhemispheric transfer of information for its successful performance, namely continuous use of feed forward as well as feedback information about component movements (Kalat, 1995; Jeeves, 1990). The significant differences shown between HECP and control children could provide further support for a dysfunctional corpus callosum, however, in the light of the difficulty already addressed in locating function it has to be appreciated that these findings could also be a consequence of right hemisphere insufficiency (for review see Banich, 1995).

'Threading nuts on bolt'. In the ABC test battery, from which this test is taken, children are required to hold the bolt with their non-preferred hand and provide the action with their preferred hand. By adding a second condition in which the function of the two hands was reversed, it was possible to provide findings much more relevant to the question on hand. The finding of significant differences on this task between the HECF and the control children (aged 8 years) when the left hand (non-preferred hand) was used for screwing the nuts on supports the proposition that the HECF children have, mainly, a left hand (right hemispheric) competence problem (Sigmundsson, 1999). Remember, however, that the 'threading nuts on bolt' task, in the manner prescribed, is a purely distal¹ task and dependent upon which hand is being used for the action, controlled by the contralateral hemisphere (Jeannerod, 1988; Shafer, 1993). Asymmetry in performance was also shown between the hands in the HECF group of children but not in children with no apparent hand-eye co-ordination problems (Sigmundsson, 1999).

These findings, it might be speculated, suggest that insufficiency within the right hemisphere, with or without a dysfunctional corpus callosum, could be a possible factor contributing to the problems that motor-impaired children are reported to encounter in more complex everyday fine-motor skills like needlework, dressing, doing up buttons, and shoelaces etc. (for a review see Smyth, 1992) and in 'almost' every task when temporal constraints are imposed.

Analyses using lateralization-dependent variables showed a marked difference between the performances of the two hands in the HECF groups only, in favor of the right hand (preferred hand). The lateralization effect has only received minimal

attention by research workers in this field, one of the exceptions being that of Armitage and Larkin (1993), who found a higher prevalence of crossed dominance in clumsy populations. Thus, the results of earlier studies in which scores derived from only the preferred hand or a combination of both hands was used (Laszlo & Bairstow, 1985; Bairstow & Laszlo, 1981; Smyth, 1991, 1994; Hulme et al., 1982a,b, 1984; Murphy & Gliner, 1988; Williams et al., 1992; Henderson et al., 1992, Henderson et al., 1994), might, on the basis of the findings reported here, need to be qualified.

CONCLUSION

Previous research on perceptual deficits involving clumsy children have been confined to identifying deficits in particular abilities without any attempt to tease out their underlying mechanisms or causal links between underlying neural processing and behavior (Sigmundsson et al., 2002). Achieving the latter requires a process-oriented approach, which attempts by appropriate experimentation to tease out the ways in which these children organize their actions in time and space. This approach, grounded in a multi-disciplinary framework, has been the departure point for recent research in our group.

We suggest that the findings from our studies are behavioral manifestations of a putative neurological abnormality. This notion then raises the question of causation. The etiology of clumsiness has, generally, been couched in terms of nature versus nurture: prenatal or perinatal brain damage or limitations in postnatal experience. Dare and Gordon (1970) noted that clumsy children are often classified as having minimal cerebral dysfunction, or minimal brain damage. This view is supported by Gubbay (1975) and Hadders-Algra (2000) who argue that a continuum of neurological damage underlies motor impairment, and that an overlap

¹ Although, the distal/proximal distinction will not be pursued here, it has recently been the focus of experimental work on motor impaired children by Sigmundsson et al., (1999b).

exists between cerebral palsy (a condition manifested by poor control of movement (Stanley & Alberman, 1984) and clumsiness. Sugden and Keogh (1990) pointed out that: 'In all cases of cerebral palsy there is a evidence of brain damage as the basic cause of the problem, although location of the damage often cannot be specified' (p. 11).

In the studies reported in the present article, the children with HECP have particular problems in using the non-preferred hand in both sensory integration and visual motor tasks (threading nuts onto a bolt). This result suggests that the default argument (minimal brain damage) pursued by Dare and Gordon (1970) and Gubbay (1975) might have to be revisited. Lack of experience may also be a reason why the functioning of these children might be deficient (Bairstow & Laszlo, 1989; Henderson, 1992). If, for example, the children with HECP use their nonpreferred hand only minimally, then one consequence might be that the hemisphere controlling that hand will develop differentially from the hemisphere controlling the preferred hand (for overview see Bogen, 1990). Nevertheless, cause and effect, in this case, is difficult to determine: inherent processing difficulties in the hemisphere controlling the nonpreferred hand may lead to avoidance of the use of the hand wherever possible. Such avoidance, in turn, may further delay or limit the development of inter-callosal communication (Preilowski, 1972, 1990; Jeeves, 1990). Thus, a vicious circle of limited use and limited development may ensue.

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