The association of an omitted crawling milestone with pencil grasp and control in five- and six-year-old children

Magrieta Maria Visser, MSc Occupational Therapy (Wits)
Lecturer, Department of Occupational Therapy, Faculty of Health Sciences
University of the Free State

Denise Franzsen, MSc Occupational Therapy (Wits)
Lecturer, Department of Occupational Therapy, Faculty of Health Sciences, University of the Witwatersrand

ABSTRACT

Children seen in occupational therapy for pencil grasp and control problems are often identified, based on parents' information, as having omitted crawling milestones. This study investigated the possible association between an omitted crawling milestone and pencil grasp and control. A case-control study compared 30 children aged 5–6 years old with omitted crawling as infants, with a matched group who did crawl. The Developmental Test of Visual Perception (DTVP-2) and a pencil grasp observation were used to assess pencil grasp and control. Statistically significant differences were found between the crawlers and the non-crawlers with regard to pencil grasp and visual perception, but not for pencil control. Limitations of the study included a small sample, a broad definition of omitted crawling and a non-standardised assessment of pencil grasp. Further research on factors causing omitted crawling, its impact on other areas of development, and the development of a pencil control assessment tool, is recommended.

Key words: crawling milestone; pencil grasp; pencil control; visual perception; age 5–6 years

Introduction and literature review

Crawling, defined as reciprocal locomotion on the hands and knees while lifting the trunk from the floor[1], is a developmental milestone for infants, and usually starts to occur from around seven months and is mastered at about nine months of age. Crawling consists of reciprocal extremity movements and trunk counteractions. Independent weight shifting on the extremities as well as the ability to elevate the trunk from the floor are required[1]. Crawling becomes an infant's primary means of locomotion to explore his/her environment and to obtain and transport toys. Infants continue to crawl for a period of four to six months until the ability to walk independently is developed at approximately 12 months of age. Literature indicates that crawling is not only a preparation for walking but a multifaceted process assisting in the development of many components such as body scheme, motor planning, visual perception and eye-hand coordination[2–6]. Thus reduced input associated with limited crawling can affect certain areas of development.

Research has shown that factors such as the quality of upper limb function related to tactile, proprioceptive and kinaesthetic skills[2] and performance at a preschool level[7] can be affected by a lack of crawling. These studies emphasised the importance of crawling in the development of sensory and motor systems and motor skills[2,7].

Chapelais and Macfarlane[7] assert that less than two months of crawling is not sufficient to establish the skills needed in the upper limbs, and these children along with those who fall into the group described as "early walkers" were included in the non-crawling group[7]. Based on work by Bottos *et al*.[8], children with a totally omitted crawling milestone as well as those who bum shuffle and use other patterns of locomotion (except walking) such as moving sideways without bearing weight on straight arms or on their backs or stomachs, are also regarded as non-crawlers. For every 24 hours of walking ring use, the onset of crawling, standing alone and walking can be delayed by 3.3 to 3.7 days, showing a strong association between the amount of use of such devices and the extent of developmental delay[9]. This type of equipment is extensively used in the middle class socioeconomic group[10], with up to 54% of infants placed in walking rings from 26 to 54 weeks of age. A minimum of two hours a day over a possible 28-week period (392 hours in total) was considered problematic enough to interfere with crawling in this study[7].

From clinical experience, many children seen in occupational therapy for having pencil grasp and control problems were identified from parent background information as having omitted crawling milestones. An efficient pencil grasp is defined as a mature, functional grasp in order to hold a pencil, such as dynamic tripod pinch[11,12] and for the purpose of this study, pencil control is defined as the subtle adjustments of the fingers and hand when holding a pencil, in order to write in a coordinated, smooth manner. It is dependent on adequate in-hand manipulation and dexterity.

This raised the question, which became the purpose of this study, of whether a decreased period or an absence of crawling is reflected in the development of the child's fine motor skills, especially with regard to pencil grasp and control. The objectives of this study were, firstly, to establish the difference in quality of pencil grasp in children who crawled and those who did not crawl, by means of a pencil grasp observation form; and secondly, to investigate the difference in the quality of pencil control between children who crawled and those who did not crawl, by using the eye-hand coordination subtest of the Developmental Test of Visual Perception (DTVP-2).

No literature specifically describing the association between crawling and pencil grasp and control was found, which further supported the motivation to undertake this investigation. This literature review describes how crawling contributes to the developmental components of hand function, with specific emphasis on the components needed for pencil grasp and control. These components include proximal joint stability, proximal joint mobility, arches of the hand, motoric separation of the two sides of the hand, and open web space and thumb movements.

Proximal joint stability: The development of fine motor skills depends on the interaction of all the joints of the upper extremity, which includes the scapulo-thoracic, gleno-humeral, elbow and wrist joints. Every proximal joint must provide a stable base of support (stability) for the joints distal to it to enable maximal control. Proximal joint stability of the shoulder, elbow and wrist is therefore needed for distal finger skills and other dexterous hand skills. During the process of crawling, development of arm muscles and proximal joint stability occurs[12].

Proximal joint mobility: Every joint must move freely into its mature patterns, with adequate mobility. The long finger flexors slowly become lengthened over the wrist and through the palm when the baby rocks back and forth in the quadruped position and when pulling forward in crawling, preparing the wrist to move in full range of extension and stimulating finger movements. A stable, extended wrist is needed to pull the fingers into flexion, assisting in the hand's ability to grasp small objects such as a pencil (known as the tenodesis process)[13]. Full wrist extension is also sometimes needed, depending on the angle of the writing surface[14].

Arches of the hand: Two transverse, four longitudinal and four diagonal or oblique arches are involved in the anatomy of the hand. The arches are significant for (a) shaping the hand to grasp multiple shaped and size objects, (b) directing skilled movements of the fingers, and (c) grading the power of prehension (seen in pencil grasp and control). Palmar arches form part of the proximal control of the hand that leads to distal control of the fingers[12]. Crawling and its weight-shifting components provide input into the hand, which contribute to the development of the palmar arches. Forward and backward rocking in the quadruped position facilitates the development of longitudinal arches. Lateral weight shift also contributes to the development of the transverse and oblique arches of the hand[1].

Motoric separation of the two sides of the hand: Refinement of skills within the radial side of the hand is best achieved when the ulnar side of the hand is stabilised. When digits four and five are flexed against the palm or are in extension, combined with abduction of the little finger, this will stabilise the transverse metacarpal arch and localise control to fingers two and three. With this separation, the radial or skilled digits can manipulate more precisely with the thumb[12]. Hand separation starts when the infant crawls and bears weight on the ulnar side of the hand while carrying toys with the radial digits[12].

Open web space and thumb movements: For optimal distal manipulation, the thumb must move into full abduction with medial rotation to gain stability to work opposite any distal finger tip. At the full range this complex saddle joint will be stabilised by the joint ligaments, the combined action of the long and short extensors, the long abductors, the flexor and adductor. This thumb position allows opposition to all finger tips for delicate manipulation, with assistance of the transverse metacarpal arch. From this posture the triad muscles, those most densely supplied with receptors, will guide movements and regulate the pressure for speed and dexterity[12]. Weight shifting when crawling also elongates the web space between the thumb and index finger, creating more room for objects during grasp – a prerequisite for a tripod grasp with open web space. It also stimulates active stabilisation of the thumb[14].

The hand expands or flattens itself during weight bearing in quadruped positions, crawling and bear-walking. Hand expansion is a prerequisite to grasp, manipulation and release objects[14]. As the infant crawls and rakes at objects, his eyes are intent on his fingers. Sensory integration is taking place between vision and proprioception, which is the beginning of eye-hand coordination and forms an integral part of pencil control[15].

According to Edwards *et al*[5], many other factors must work together in addition to crawling in order for hand function to develop optimally. Examples of such factors contributing to the development of a mature grasp include postural control, motor planning, eye-hand coordination, tactile and proprioceptive input, and somatosensory processing[5].

From this literature review one is able to understand the important role of the weight bearing component of crawling for the development of hand function and grasp in preparation for fine manipulation although some weight bearing may occur in other forms of infant locomotion.

Although this study focused mainly on crawling and the possible correlation between omitted crawling and pencil grasp and control, the authors were aware that this was not necessarily a causal relationship, and factors that resulted in the lack of crawling might be related to the other deficits found in this study. Also, in attempting to establish a possible correlation between crawling and the other variables, it could not be assumed that the development of these variables was dependent only on crawling or the development of gross motor function[16].

Methodology

The research design was a cross-sectional, case-control study. A group of children who had not crawled were to be compared to a group who had crawled in order to establish a possible relationship between their crawling status and pencil grasp and control. The non-crawling children were matched with the crawling children in terms of gender and age. Ethical clearance to perform the investigation was obtained from the Committee for Research on Human Subjects at the University of the Witwatersrand.

Based on convenience with regard to travel cost and time, children from 29 pre-schools and primary schools were selected in an area which represented a middle socioeconomic stratum of an urban population in Northern Johannesburg. The schools were selected if they were willing to participate, had a grade 0 or R class and if the children in the school had been exposed to pencil and paper activities. Parent information forms, consent forms and questionnaires were sent to either the father, mother, guardian or caregiver of all 1200 children aged five to six years in the 29 schools included in the study. The aim of the parent questionnaire was to obtain enough information on the child's early development, in order to classify the children into a crawling or non-crawling group. The questions that were asked covered aspects of crawling such as did your child crawl, for how long, was there anything strange about your child's crawling, did he/she use a walking ring/jolly jumper?

The low number of participants who totally omitted crawling resulted in the definition of omitted crawling being extended. Consequently, in addition to total omission of crawling, children were classified as non-crawlers when a combination of the following atypical crawling methods and behaviour was displayed:

- crawling for less than two months;
- avoided crawling;
- "lazy" crawling;
- wanting to be picked up most of the time;
- showing difficulties with crawling;
- employing awkward movement patterns, for example sideways, on the back or stomach;
- crawling did not occur on all four limbs;

- using bum shuffling more than crawling as means of locomotion;
- using equipment such as a jolly jumper or walking ring for more than two hours per day.

Despite the fact that some of these children did crawl to a limited extent, or performed "crawl-like" movements, all these modes of locomotion were categorised as omitted crawling in this study.

In contrast the subjects qualified for the crawling group if they crawled for two months or more; used all four limbs to crawl from one point to the other; there was no awkwardness mentioned about their crawling; did not bum shuffle most of the time instead of crawling; and did not use a jolly jumper or walking ring for long periods on a regular basis (more than two hours per day).

After the 30 non-crawlers were identified from the 268 returned forms, they were matched with 30 crawlers in terms of gender and on birth date to within two months. The children were paired irrespective of the school they attended as it was not possible to match children at the same school.

These 60 participants were then assessed by the researcher who was blinded to the child's crawling status as this information was not available to her at the time of the assessment.

The subjects were tested at their own schools in an allocated room, appropriate for testing, by the researcher. To eliminate variables in testing the subjects, the following measures were taken:

- each subject used the same pencil, sharpened before he/she started;
- the same testing book and response booklets were used for all the children;
- correct table and chair size for the 5 and 6 year olds were used i.e. the knees were flexed at 90 degrees and the feet supported on the floor or on a raised surface. Table heights were not too high, and supported the elbows at a 90 degree angle;
- the room was free of distractions and with adequate light and ventilation. All the testing materials were prepared in advance by the researcher, such as sharp pencils and test booklets.

The subjects were tested individually by the researcher and the test was presented in their home language.

The first measurement tool used with each child was the revised Developmental Test of Visual Perception (DTVP-2)[17]. The DTVP-2 consists of a battery of eight subtests that measure visual perceptual and visual-motor abilities, including eye-hand coordination, position in space, copying, figure ground, spatial relations, visual closure, visual motor speed and form constancy. Each of the eight subtests is divided into either motor-reduced or motor-enhanced composite scores.

To assess pencil control, the eye-hand coordination subtest of the DTVP-2 was used. One of the limitations of this test is that although it is valid and reliable for testing eye-hand coordination, it is not specifically designed to test pencil control. However, in comparison with other standardised tests available to occupational therapists, the DTVP-2 has very specific scoring criteria for measuring the control of a pencil between lines, and was therefore used.

Secondly, a pencil grasp observation form was developed for this study based on several pencil grasp classifications, of which the Benbow pencil grasp observation could be regarded as the most useful[12]. This form was used to identify efficient and inefficient pencil grasps while the children were engaged in the motor-enhanced subtest of the DTVP-2 test. A two-point scale was used where a score of zero (0) was allocated to an efficient pencil grasp, and one (1) to an inefficient pencil grasp.

Results and Discussion

Of the 1200 number of forms sent out to 29 schools, the parents of 268 children responded by completing the questionnaire and gave written consent for their children to participate in the study, giving a return rate of 22.3 % which correlated with the average return rates in research studies[16].

A total of 60 children from the 268 responses (30 crawlers and 30 age and gender matched non-crawlers) participated in the study. Twenty-six (43.3%) participants were male. With regard to age, 34 (56.7%) children were five years old, while the remaining 26 (43.3%) were six years of age. The distribution of crawlers and non-crawlers with regard to gender and age is shown in *Table I*.

Table I: Demographics of crawling and non-crawling children with regard to gender and age.

Variable	**Crawlers (n=30)**	**Non-crawlers (n=30)**
Gender		
Male (n=26)	13	13
Female (n=34)	17	17
Age		
5 years (n=34)	17	17
6 years (n=26)	13	13

Since the sample was evenly distributed in terms of these two variables, all data were analysed. The distribution of the different types of atypical crawling identified in non-crawlers is shown in *Table II*.

Table II: Distribution of different categories of non-crawling.

Crawling status	**Number of non-crawlers (%) (n=30)**	**% of total sample (n=268)**
Total non-crawlers	30 (100.0)	11.2
Omitted crawling	11 (36.7)	4.1
Atypical crawling	19 (63.3)	7.1

The percentages of different modes of locomotion observed in non-crawlers (*Table II*) were found to be lower but not remarkably different from other research findings. In a group of non-crawlers, Bottos *et al*[8], found that 12% of these children did not crawl at all (comparing to 4.1% in this study) and just stood up and walked, while 9% bum shuffled and 4% used other patterns, such as stomach creeping (both considered as atypical crawling). This compared to 7.1% in this study.

Questionnaire results revealed that 23 (38.3%) of the 60 children used supplementary locomotion equipment such as jolly jumpers and/or walking rings on a regular basis when they were infants. The parents used terms such as "a lot", "daily", "very often", "4–5 hours a day", "in the afternoons" and "always" to indicate how often these apparatus were used. The questionnaire was limited in the collection and possible interpretation of this data as no clear options were provided to select. Consequently, data were grouped according to the answers given and were difficult to analyse accurately. The use of jolly jumpers and walking rings is shown in *Table III*.

Table III: The use of jolly jumpers and/or walking rings.

Frequency of use	**Number of children (n=60) (%)**	**Number of crawlers**	**Number of non-crawlers**
Frequently but less than two hours per day	23 (38.3)	8	15
Occasionally	21 (35.0)	11	12
Never	16 (26.7)	9	7

Almost twice as many non-crawlers (15 compared to eight crawlers) frequently used supplementary locomotion equipment. This correlates with findings in literature[9,19] that indicates that the use of such equipment has a negative effect on motor milestones.

The results with regard to pencil grasp are shown in *Table IV* on page 22. Fourteen (82.4%) of the children with inefficient pencil grasp were non-crawlers, as opposed to only three (17.5%) of the crawlers who displayed inefficient pencil grasp. Fisher's exact test

Table IV: Comparison of the crawling and non-crawling groups with respect to pencil grasp.

Pencil grasp	Number of crawlers (n=30)(%)	Number of non-crawlers (n=30) (%)	Total (n=60) (%)
Efficient	27 (90)	16 (53.3)	43 (71.7)
Inefficient	3 (10.0)	14 (46.7)	17 (28.3)

indicated that the proportion of children with poor pencil grasp among crawlers was significantly less (p= 0.003) than among non-crawlers (10.0% and 46.7%, respectively). The crude odds ratio for pencil grasp when exposed to crawling is 7.88, i.e. the risk of an inefficient pencil grasp is a 7.88-fold increase for non-crawlers when they are compared to crawlers and the 95% confidence interval is (1.96;31.68).

These findings suggest that there may be a possible link between omitted crawling and the development of mature hand function resulting in an efficient pencil grasp. Children, who did not crawl or displayed atypical crawling patterns, appeared to have inefficient pencil grasp in comparison to children who did crawl. Therefore, it could be postulated that the reason for this might be that the basic motor components established during the crawling phase of motor development did not develop sufficiently if the child did not crawl. The observation used for pencil grasp, although rigorous, was not a standardised test and might have under- or over-evaluated efficient pencil grasp, which could be regarded as a limitation of the study.

With regard to observations on pencil control and the DTVP-2 eye-hand coordination subtest, no statistically significant difference between crawlers and non-crawlers was found. It was expected that the non-crawlers would score lower than the crawlers in the eye-hand coordination subtest, as this subtest requires a substantial amount of in-hand manipulation and dexterity to achieve pencil control[16,20]. The eye-hand coordination subtest of the DTVP-2 was therefore probably not the most effective pencil control assessment tool and proved to be a limitation of the study. The addition of other eye-hand coordination tests, such as the revised Beery Buktenica Test of Motor Coordination[21] or the motor accuracy subtest (MAC) of the Sensory Integration Postrotary Nystagmus Test (SIPT)[22] could have been of more value to the study. It is therefore strongly recommended that these instruments should be considered in future research in this particular field.

Pertaining to the association between visual perception and crawling, the analysis of the subtest results indicated that the spatial relations subtest was the only subtest that had a statistically significant difference between the crawling and non-crawling group (p=0.04). The crawlers had significantly higher scores than the non-crawlers. The p-values for other subtests ranged from p=0.08 to p=0.79. It could be assumed that all the visual, proprioceptive, tactile and vestibular input the baby received in the horizontal orientation while crawling, might be related to this finding.[4,6] The differences between the crawlers and non-crawlers on the subtests of the DVPT-2 are shown in *Table V*.

The composite scores of the DTVP-2 were compared for the two groups using the Welch t-test and the Mann-Whitney test. The crawlers had significantly higher scores than the non-crawlers in all three of the composite scores: (i) the general visual perception quotient (GVPQ) score is a composite score of the eight subtests of the DTVP-2 (p=0.02); (ii) in the motor-reduced visual perception quotient (MRVPQ), which includes all the motor-reduced visual perception subtests, (p=0.04); and (iii) the visual-motor integration quotient (VMIQ), which consists of motor-enhanced aspects (involving written output) (p=0.03). *Table VI* shows the DTVP-2 composite scores obtained by the crawling and non-crawling groups.

The results shown in *Table VI* indicate that crawling might play an important role in the development of visual perception skills, more specifically the spatial relations aspect thereof. This observation is consistent with the findings of McEwan *et al*.[2], although the question whether deficits in visual perception skills could be considered as the underlying reason why some children do not crawl, could not be resolved. The results of the study suggest that there might be a link, but it should be emphasised that such a supposition needs to be interpreted with care, and further research in this area is warranted.

Conclusion and Recommendations

The results of the study suggest that there may be a link between an omitted crawling milestone and the development of pencil grasp in five- and six-year-old children. Efficient pencil grasp among the crawlers was significantly better than among the non-crawlers, although no significant difference was found on the coordination test used to observe pencil control. However more research is needed to explore this.

An unexpected finding, although beyond the original scope of the study, was the association observed between an omitted crawling milestone and the development of visual perception. Crawlers

Table V: Differences between the crawlers and the non-crawlers on the subtests of the DVPT-2 test.

Measured subtests	Crawlers (n=30)			Non-crawlers (n=30)			p-value[c]
	Mean	SD[a]	95% CI[b]	Mean	SD[a]	95% CI[b]	
Eye-hand coordination	9.20	0.89	[8.87 ; 9.53]	9.13	1.04	[8.74 ; 9.52]	0.79
Position in shape	9.83	1.93	[9.11 ; 10.55]	8.93	2.00	[8.19 ; 9.68]	0.08
Copying	11.30	2.32	[10.43 ; 12.17]	10.67	1.47	[10.12 ; 11.22]	0.23
Figure ground	10.73	2.09	[9.94 ; 11.52]	10.00	2.19	[9.18 ; 10.82]	0.19
Spatial relations	11.83	3.07	[10.69 ; 12.98]	10.40	2.11	[9.61 ; 11.18]	0.04*
Visual closure	8.07	2.24	[7.22 ; 8.90]	7.33	2.04	[6.57 ; 8.09]	0.19
Visual motor speed	11.10	2.22	[10.27 ; 11.93]	10.43	1.73	[9.78 ; 11.08]	0.20
Form constancy	11.93	1.44	11.39 ; 12.47]	11.70	1.09	[11.29 ; 12.10]	0.48

[a]SD = standard deviation; [b]CI = confidence interval; cdetermined by means of Fisher's exact test; *statistically significant

Table VI: Comparison of the DTVP-2 composite scores for the crawling and non-crawling groups.

DTVP-2 composite scores	Crawlers		Non-crawlers		p-value[b]
	Mean	SDa	Mean	SDa	
General visual perception quotient (GVPQ)	103.6	8.43	98.8	6.25	0.02*
Motor-reduced visual perception quotient (MRVPQ)	100.9	8.33	96.6	7.41	0.04*
Visual-motor integration quotient (VMIQ)	105.7	9.77	101.0	6.71	0.03*

[a]SD = standard deviation; [b]determined by means of Welch t-Test and Mann-Whitney Test; *statistically significant

performed significantly better on all three composite scores and one subtest, namely spatial relations, of the DTVP-2.

Certain limitations of the study should be taken into account when the results are interpreted. Firstly, the definition and categorisation of omitted crawling initially proved to be more difficult than expected, and atypical methods of locomotion were included to expand the sample size of the non-crawling group. Secondly, a non-standardised observation form was used as a measuring tool to assess pencil grasp. Thirdly, pencil control was assessed by means of the eye-hand coordination subtest of the DTVP-2, although this specific subtest is not necessarily suitable to assess pencil control. Consequently, this shortcoming led to the question whether this subtest was sufficiently sensitive to detect pencil control difficulties, and would the use of a combination of tests more appropriate to assess pencil control, have yielded different results.

Similar to many research attempts, more questions than answers have been created by this investigation. More research is recommended to equip parents, health and educational professionals with more knowledge about the importance of crawling and why some children do not crawl. Further investigation into the impact of crawling on other areas of development with more children included in the study is warranted, as well as identification of specific factors contributing to the omission of typical hands-and-knees crawling. Standardised assessment tools for pencil grasp and pencil control in normal children also need to be developed and evaluated. The DTVP-2 should be used with care on the South African population with its wide cultural diversity, as further research is needed to standardise this instrument for South African circumstances.

Awareness should be increased about the advantages and disadvantages of using supplementary locomotion equipment (with particular reference to jolly jumpers and walking rings) that limit and/or replace the natural development of crawling. The importance of crawling and creating ways to stimulate crawling should also be addressed in both scientific and popular literature.

Acknowledgments

Daleen Struwig, medical writer, Faculty of Health Sciences, University of the Free State, for technical and editorial preparation of the manuscript for publication.

References

1. Bly L. An illustrated guide to normal development. Arizona: Therapy Skill Builders, 1994.
2. McEwan MH, Dihoff RE, Brosvic GM. Early infant crawling experience is reflected in later motor skill development. Perceptual Motor Skills 1991; 72:75-79.
3. Colangelo CA. Normal baby. The sensory-motor processes of the first year. New York: Valhalla Rehabilitation Publications, 1986.
4. Clearfield MW. The role of crawling and walking experience in infant spatial memory. Journal of Experimental Child Psychology 2004; 89:214-241
5. Edwards SJ, Buckland DJ, McCoy-Powlen JD. Developmental and functional hand grasps. New Jersey: Slack Incorporated, 2002.
6. Ayres J, Robbins J, McAfee S. Sensory integration and the child: understanding hidden sensory challenges. 25th anniversary ed. Los Angeles: Western Psychological Services, 2005.
7. Chapelais JD, Macfarlane JA. A review of 404 “late walkers”. Archives of Disease in Childhood 1984; 59:512-516.
8. Bottos M, Della Barba B, Stefani D, et al. Locomotor strategies preceding independent walking: prospective study of neurological and language development in 424 cases. Developmental Medicine and Child Neurology 1989; 31:25-34.
9. Garrett M, McElroy AM, Staines A. Locomotor milestones and babywalkers: cross sectional study. British Medical Journal 2002; 324:1494.
10. DiLillo D, Damashek A, Peterson L. Maternal use of baby walkers with young children: recent trends and possible alternatives. Injury Prevention 2001; 7:223-233.
11. Case- Smith J. Occupational therapy for children. 5th ed. Missouri: Elsevier/Mosby, 2005.
12. Benbow M. Neurokinesthetic approach to hand function and handwriting. Albuquerque: Clinician’s View, 1995.
13. Greene DP, Roberts SL. Kinesiology: movement in the context of activity. Missouri: Elsevier/Mosby, 2005.
14. Boehme R. Improving upper body control. An approach to assessment and treatment of tonal dysfunction. Arizona: Therapy Skill Builders, 1988.
15. Horton ME. 1971. The development of movement in young children. Physiotherapy 1971; 57:149-153.
16. Rosenblum S, Josman N. The relationship between postural control and fine manual dexterity. Physical and Occupational Therapy in Pediatrics 2003; 23:47-57.
17. Hammill DD, Pearson NA, Voress JK. Developmental test of visual perception. Texas: Pro-Ed, 1993.
18. Prairie Research Associates (PRA Inc). “Response rates on mail surveys”. 2001. (http://www.pra.ca/resources/rates_e.pdf) (Accessed 6 August 2004).
19. Siegel A, Burton R. 1999 Effects of babywalkers on early locomotor development in human infants. Developmental and Behavioral Pediatrics 1999; 20:355-361.
20. Humphry R, Jewell K, Rosenberger RC. Development of in-hand manipulation and relationship with activities. Australian Journal of Occupational Therapy 1995; 49:763-771.
21. Beery K. The Beery-Buktenica developmental test of visual- motor integration. 4th ed. rev. New Jersey: Modern Curriculum Press, 1997.
22. Ayres AJ. Sensory integration and praxis test manual, updated ed. 8th print. Los Angeles: Western Psychological Services, 2004. ❑

Corresponding Authors

Magrieta Maria Visser
vissermm.md@ufs.ac.za
Denise Franzsen
denise.franzsen@wits.ac.za