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Assessment of sensorimotor functions after traumatic brain injury (TBI) in childhood – Methodological aspects

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Abstract

Various basic qualitative and quantitative methods for the evaluation of sensorimotor functions after Traumatic Brain Injury (TBI) are introduced and discussed.

Methodological aspects are illustrated by a single case follow-up study of a child after severe TBI (age 11; 7–12;1 yrs; 6, 8 and 12 month post TBI) in comparison to an age-matched healthy control group (N = 16).

The evaluation consisted of neurological investigation, Barthel-Index, Terver Numeric Score for Functional Assessment, Rappaport Disability Rating Scale (modified version), a coordination-test for children (KTK), a pilot-tested Motor Function Score, quantitative evaluation of spatiotemporal gait parameters on a walkway and on a treadmill, and the kinematic assessment of hand motor functions.

Quantitative movement analyses revealed two general types of motor disorder: Slowing of movements and compensatory motor strategies. Averaged z-scores showed deficits, which were pronounced in fine motor skills (hand movements: 1.86, gait: 1.3). During follow-up, a strong improvement rate during the first (–0.48 z-scores) and nearly no improvement rate (–0.03 z-scores) during the second time interval was seen. Clinical scores and developmental tests were not able to document the whole restitutional course, whereas motor tests with special emphasis on functional aspects and the quantitative movement assessment seemed to be suitable methods.

We conclude that a sufficient evaluation of sensorimotor functions after TBI in childhood needs an increase in procedural uniformity on one hand and the combination of various qualitative and quantitative methods on the other hand. To connect both claims, further research is necessary.

Keywords: traumatic brain injury, sensorimotor functions, functional restitution, children

1. Introduction

Sensorimotor functions, which often are severely affected in brain damaged children, show in many cases a surprising restitution over time. This functional restitution must be differentiated from the age-dependent ontogenetic maturation of motor functions [11,12,16,20,23,25,34]. For the planning of the rehabilitative strategy and for a prospective judgement of the rehabilitative course a fundamental knowledge of the capacity, sequence and velocity of the restitutional processes of various sensorimotor subfunctions is necessary [5,7,13, 22].

When we started to investigate the extent and the course of such restitutional processes in children in first pilot studies (20 children after severe TBI; research project Functional Restitution of Sensorimotor and Cognitive Functions in Brain Damaged Children), we were confronted with the

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great variety of methodological concepts in the literature and the lack of procedural uniformity in describing these events [26]. This impeded the comparison of data and results between the different groups and institutions.

In our study we have used two basic methodological approaches to document the motor dysfunctions and their recovery in children. We have combined well established qualitative and semiquantitative tests (clinical scores, neurodevelopmental test [2,19,24,28]) with several methods of quantitative movement analyses [4,14,15] which have been adapted for that purpose [17,30,31]. It became evident that the inhomogeneity of the patient group regarding the morphological criteria, the initial functional motor status and the velocity of the restitutional course restricts the use of one and the same standardized test in each patient of the group. It further appeared that the use of developmental motor tests to describe the restitutional course after traumatic brain injury is not possible in many children because of arising bottom effects.

Based on this experience we have therefore combined a variety of methods to evaluate sensorimotor functions after traumatic brain injuries. Partly these methods have been developed in our group [17,30,31], partly they are described in the literature [2,4,14,15,19,24,28]. General motor functions were assessed with an accurate neurological investigation, several clinical scales of daily living activities [2,19,24], a developmental motor test (KTK) [28] and a pilot tested motor function measure score. The specialized motor functions of gait and prehension were evaluated with quantitative methods, those of gait both on a walkway and on a treadmill, those of prehension while reaching towards a target. At present these tests are being developed further and standardized in large groups of normals and patients. These various approaches will be illustrated by a single case follow-up study of a child suffering from severe TBI. The results and methodological aspects will be discussed.

2. Material and methods

2.1. Methods to evaluate sensorimotor functions after TBI

Neurological investigation: An accurate neurological investigation is the unrenounceable base for further evaluations.

Clinical scores and a developmental test: Three established clinical scores of daily living activities and one developmental motor test have been used.

2.1.1. Barthel-Index [19]

Very well established global index of daily living activities, which comprises the following ten items: feeding, moving from wheelchair to bed and return, personal toilet, getting on and off toilet, bathing self, walking on level surface, ascend and descend stairs, dressing, controlling bowels, controlling bladder.

Range of values: 0 (dependent) – 100 (independent). The Barthel-Index is an easily applicable score with a high level of validity, intra- and interrater reliability and responsiveness [6,18]. It is usable in children and adults.

2.1.2. Terver Numeric Score For Functional Assessment [2]

A score concerning essential aspects of daily living activities including following five items: independence, communication, activities of daily living, mobility, walking.

Range of values: 0 (severe impairment) – 25 (no impairment). In contrast to the Rappaport disability rating scale this score gives special emphasis on childlike aspects, because it has been developed to investigate the course of impairments in children with cerebral palsy. Unfortunately no informations concerning the validity are available.

2.1.3. Rappaport Disability Rating Scale (modified version) [24]

Scale, which has been created to document the restitutional course of adults after TBI. Therefore little adaptions to children have led to the following six items: eye opening, best verbal response, best motor response, cognitive ability for feeding, toiletting and grooming, level of functioning, employability substituted by school-level. Range of values: 0 (no disability) …12–16 (severe disability) …30 (death). This scale is easily to perform. A significant level of predictive validity, sensitivity and reliability has been reported [10].

2.1.4. Körperkoordinationstest für Kinder KTK [28]

Established test to give a comprehensive evaluation of the developmental motor status by measuring the maximum performance in each of four exercises: balancing backward, jumping high, jumping to and fro, stepping on a bar. The test results are transformed in quotients of motor performance (MQ) with an expected mean of 100 and a standard deviation of 10. Normal values for a mixed sample of primarily and and secondarily brain-damaged children exist. Validity and reliability was sufficient. During test-standardization 91 % primary brain-damaged and 92 % mild brain-damaged children could be differentiated. The retest-reliability was given by 0.97 [28].

2.1.5. Motor Function Score

A standardized and comprehensive recording of the movement repertoire with particular emphasis on functional aspects was developed (explorative study). For this purpose a catalogue of basic movement patterns and their transitions [21] was created, consisting of the following seven groups: Stance, locomotion, sitting position, prone position, supine position, upper limbs and muscle tone. Each group includes a number of items which have to be scored using ranking scales with 2–4 levels. The total score was obtained by summing up all items. The difficulty of the required tasks was adapted to children beyond the 5^{th} year of life to avoid disturbing effects caused by continuing motor development. Because of a lack of normalized test values so far and the arising ceiling effect z-scores are not yet presentable.

2.2. Gait-analysis

2.2.1. Overground locomotion

Gait analysis was performed on a walkway according to the method described by Brinckmann [4]. In our study, the subjects traversed a walkway of 15 m length and 1 m width at their spontaneous walking speed. A thin transparent draft paper of 64 cm width was fixed along and over the central part (5 m) of the walkway. Small brass plates, prepared with punched-out peaks (like braille) were fixed under the usual walking shoes of the subjects. These peaks imprinted the subjects' footmarks on the draft paper. While walking the metal plates were not noticeable for the subjects. Spatial step parameters (stride and step lengths, step width and foot rotation angles) were measured directly from these imprints, using a drawing board.

Temporal gait parameters such as stance- and swing phase, double limb support time and gait cycle time were recorded using a video camera (50 frames/s, highspeed-shutter 0.01 s) which was equipped with a time code generator. Gait velocity was calculated using two lightbarriers. After 4 trials (20 m) spatiotemporal gait parameters were measured, averaged and transformed into z-scores [30,30].

2.2.2. Treadmill locomotion

Additionally, kinematic analysis of treadmill locomotion was performed, using an optoelectronic motion analysis system (Qualisys, Partille, Sweden). The treadmill speed was adjusted to the spontaneous gait velocity which the child showed during overground locomotion. Reflective markers were attached to the childrens' feet and legs. The spatial coordinates and displacement of these markers during treadmill walking were measured with a time resolution of 50 Hz. Data of 15–20 steps were averaged. The method has been described in detail elsewhere [30]. Referring to well known differences between overground- and treadmill-locomotion in healthy children and adults [30], a brief comparison between both methods in a child suffering from severe TBI will be presented in this study.

2.2.3. Hand movements

Functional hand movements, such as reaching and grasping, can be evaluated by quantitative kinematic recordings. In the present study, the subjects were seated in an adjustable chair. The dominant hand was kept in a defined posture (pinch position) at a starting point on the table. Upon an acoustic start signal, the children reached forward to grasp a cylindrical target object. The target position and cylinder size were adapted to the subject's arm length and finger span. The object was seized with a precision grip of thumb and index finger, and lifted. Reflective markers (half-spherical, diameter 5 mm) were attached to the nails of the thumb and index finger, and to the wrist of the reaching hand. The spatial positions of these markers were recorded by the motion analysis system. Nine kinematic parameters were calculated: Movement initiation time (MIT) lasted from the start signal until movement onset. Movement duration (MD) was the time interval between movement onset and elevation of the target object. Peak transport velocity (PV) of the hand and the maximum grip aperture (GA) attained during the reach were determined [17]. The absolute and relative timings of these events were calculated. Values of 10 trials were averaged.

A detailed description of the method and the parameters is given elsewhere [17]. The experimental paradigm was similar to the prehension task analysed in adults by Jeannerod et al. [14,15]. In addition to these kinematic recordings of reaching and grasping, fine manual functions such as threading beads were videotaped. Means and z-scores are presented.

2.3. Subjects

Patient: We present the case of an 11;7 year old schoolgirl suffering from severe TBI and polytrauma caused by a car accident. She suffered from a severe closed traumatic brain injury with traumatic subarachnoid hemorrhage, small subdural hematoma, partial infarction of the posterior cerebral artery and malignant posttraumatic brain oedema. She developed a posttraumatic hydrocephalus. The girl underwent repeated neurosurgical treatment and was treated at the intensive care unit for 7 weeks, total cerebral coma duration was 22 days. 4 weeks after the injury she showed a GCS of 7. Eleven weeks post injury she was referred to a pediatric neurorehabilitation center. She showed a spastic tetraparesis, a severe psychomotor disorder and severe neuropsychological deficits. Since then the child has been continuously enrolled in a clinical rehabilitation program. The girl has been examined by the methods outlined above 6 (t1), 8 (t2) and 12 (t3) months post injury. At the time of our first assessment, Louisa had just reached the physical and mental status to participate in the study.

2.4. Control group

The data of the patient were compared to those of an age-matched healthy control group (16 healthy children, 8 female, 8 male, age 12;0 ± 0;2 years).

3. Results

The patient's original data, her intraindividual standard deviations and the means of controls as well as their averaged intraindividual standard deviations are presented in Table 1, and Fig. 1. Table 2 displays z-values of Louisa's performance, which are illustrated in Fig. 2.

3.1. First investigation (t1)

3.1.1. Neurological findings

Louisa suffered from a severe spastic-ataxic tetraparesis with increased muscle tone of upper and lower limbs, decreased muscle tone of the trunc, bilateral considerably increased tendon reflexes with Babinski sign, severe gait-ataxia, dysdiadochokinesis and a psychomotor slowing.

TABLE 1. Scores, gait parameters and hand movements. Patient: Values ± intraindividual S.D. Investigations t1, t2 and t3 = 6, 8 and 12 months post TBI. Control group: Means ± averaged intraindividual S.D.

		Control group	***Patient***		
		Mean	***t1*** *Value*	***t2*** *Value*	***t3*** *Value*
Scores					
Barthel-Index		100 ± 0.0	100	100	100
Terver (Numeric score for functional assessment)		21 ± 0.0	12	12	14
Rappaport Disability Rating (DR) Scale		0 ± 0.0	4	4	4
KTK		94.26 ± 15.31			MQ<40, PR 0
Motor Function Score	Total:	203.75 ± 5.68	115	137	149
	Stance:	27.63 ± 1.06	12	15	17
	Locomotion:	83.75 ± 2.76	27	36	45
	Sitting position:	15.83 ± 0.74	13	13	13
	Prone position:	10.0 ± 0.0	10	10	10
	Supine position:	31.88 ± 0.35	24	30	29
	Upper extremities:	26 ± 0.0	24	26	26
	Muscle tone:	9.13 ± 1.81	5	7	9
Gait parameters					
Spatial gait parameters					
Stride length	[cm]	139.68 ± 7.62	100.86 ± 8.2	107.79 ± 5.0	115.46 ± 4.25
Step length	[cm]	70.68 ± 3.41	50.6 ± 4.62	53.83 ± 2.76	57.73 ± 2.64
Step width	[cm]	8.04 ± 2.85	10.31 ± 4.7	10.29 ± 5.18	9.29 ± 7.46
Foot angle	[°]	6.77 ± 3.76	13.60 ± 5.74	16.78 ± 4.37	10.79 ± 3.83
Right foot angle	[°]		9.14 ± 3.88	13.44 ± 3.42	10.14 ± 3.8
Left foot angle	[°]		18.50 ± 2.62	20.11 ± 2.08	11.43 ± 3.76
Temporal gait parameters					
Gait velocity	[m/s]	4.68 ± 0.28	3.36 ± 0.12	3.51 ± 0.08	3.84 ± 0.15
Cadence	[steps/min]	109.85 ± 4.97	110.54 ± 7.0	108.1 ± 0.98	107.16 ± 11.22
Stance phase	[ms]	691.2 ± 23.1	743.1 ± 39.4	718.8 ± 38.5	743.7 ± 37.1
Double limb support time	[ms]	144.2 ± 19.1	192.7 ± 38.4	173.1 ± 27.5	164.5 ± 49.8
Swing phase	[ms]	403.9 ± 22.5	360.0 ± 35.4	371.0 ± 24.9	344.4 ± 43.2
Gait cycle time	[ms]	1094.6 ± 28.1	1103.3 ± 44.7	1091.1 ± 38.8	1088.8 ± 39.4
Hand movements					
Movement initiation time	[ms]	399 ± 78	496 ± 53.1	440 ± 45.92	435 ± 55.35
Movement duration	[ms]	685 ± 67	788 ± 31.2	732 ± 29.4	735 ± 35.3
Transport parameters					
Peak transport velocity	[cm/s]	98.8 ± 5.2	75.7 ± 1.7	82.9 ± 1.1	81.7 ± 3.8
Time to peak velocity	[ms]	293 ± 26	412 ± 41.2	396.0 ± 55.7	430.0 ± 17.3
Relative time to peak velocity	[%]	42.5 ± 3.6	52 ± 0.03	54 ± 0.02	59 ± 0.03
Deceleration duration	[ms]	456 ± 38	376 ± 19.6	336 ± 34.4	305 ± 25.9
Grasp parameters					
Maximum grip aperture	[cm]	6.52 ± 0.61	10.6 ± 0.93	8.4 ± 0.79	8.02 ± 0.30
Time to max. grip aperture	[ms]	465 ± 56	612 ± 46.7	528 ± 81.6	575 ± 8.7
Relative time to max. grip aperture	[%]	67.8 ± 6.3	78 ± 4	72 ± 4	78 ± 3
Beads					
Large beads	[s]	23.33	30	25	25
Small beads	[s]	32.56	70	51	48

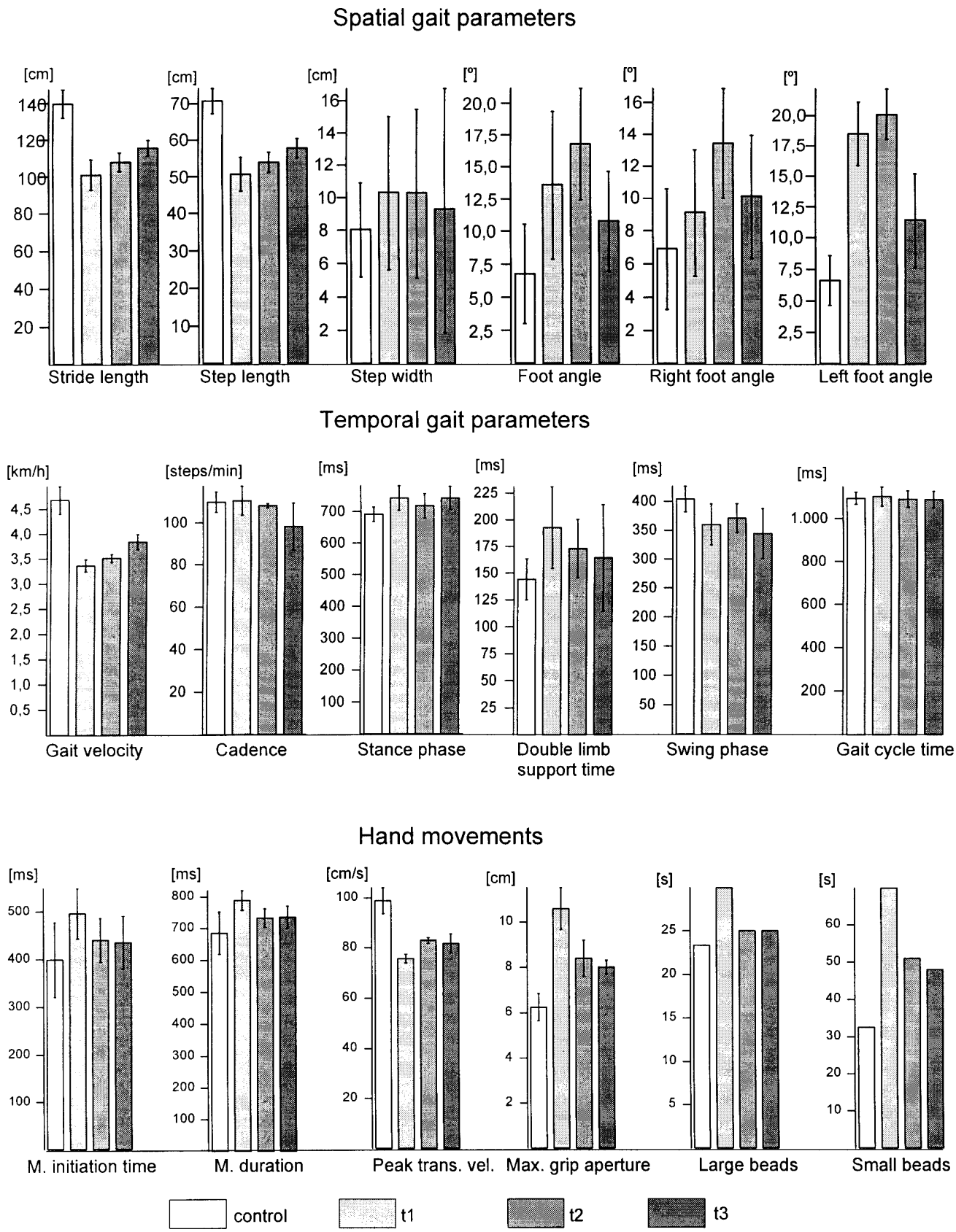

Fig. 1. Gait parameters and hand movements. Values and intraindividual standard deviation of an 11;7–12;1 year old girl after severe TBI; investigations 6 (t1), 8 (t2) and 12 (t3) months post TBI. Means and averaged intraindividual standard deviations of the control group (N = 16). In gait parameters good improvement rates during both time intervals. Improvement of hand movements only during the first period.

TABLE 2. Gait parameter and hand movements of an 11;7 – 12;1 year old girl after severe TBI. Z-scores of t1, t2 and t3 = 6, 8 and 12 months post TBI. Difference between t1 and t3.

	z(t1)	*z(t2)*	*z(t3)*	*abs(zt1)-abs(zt3)*
		Gait parameters		
Double limb support time	2.22	1.33	0.93	1.29
Step length	–2.52	–2.11	–1.62	0.89
Stride length	–1.97	–1.62	–1.23	0.74
Gait velocity	–2.00	–1.77	–1.27	0.73
Foot angle	1.70	2.5	1.00	0.70
Step width	0.73	0.73	0.40	0.33
Gait cycle time	0.07	–0.03	–0.05	0.02
Stance phase	0.66	0.35	0.67	–0.01
Swing phase	–1.07	–0.8	–1.45	–0.38
Cadence	0.06	–0.15	–0.99	–0.93
Mean (abs(z))	**1.30**	**1.14**	**0.96**	**0.34**
		Hand movements		
Maximum grip aperture	4.25	1.96	1.56	2.69
Small beads	3.73	1.84	1.54	2.19
Large beads	2.14	0.54	0.54	1.60
Movement initiation time	0.82	0.35	0.31	0.52
Peak transport velocity	–1.67	–1.15	–1.24	0.43
Movement duration	0.79	0.36	0.38	0.41
Time to max grip aperture	1.50	0.64	1.12	0.38
Rel. time to max. grip apert.	1.17	0.48	1.17	0.00
Time to peak velocity	2.09	1.81	2.40	–0.32
Deceleration duration	–0.82	–1.22	–1.54	–0.72
Relative time to peak velocity	1.53	1.85	2.66	–1.13
Mean (abs(z))	**1.86**	**1.11**	**1.31**	**0.55**
		Total		
Total Mean (abs(z))	**1.60**	**1.12**	**1.15**	**0,45**

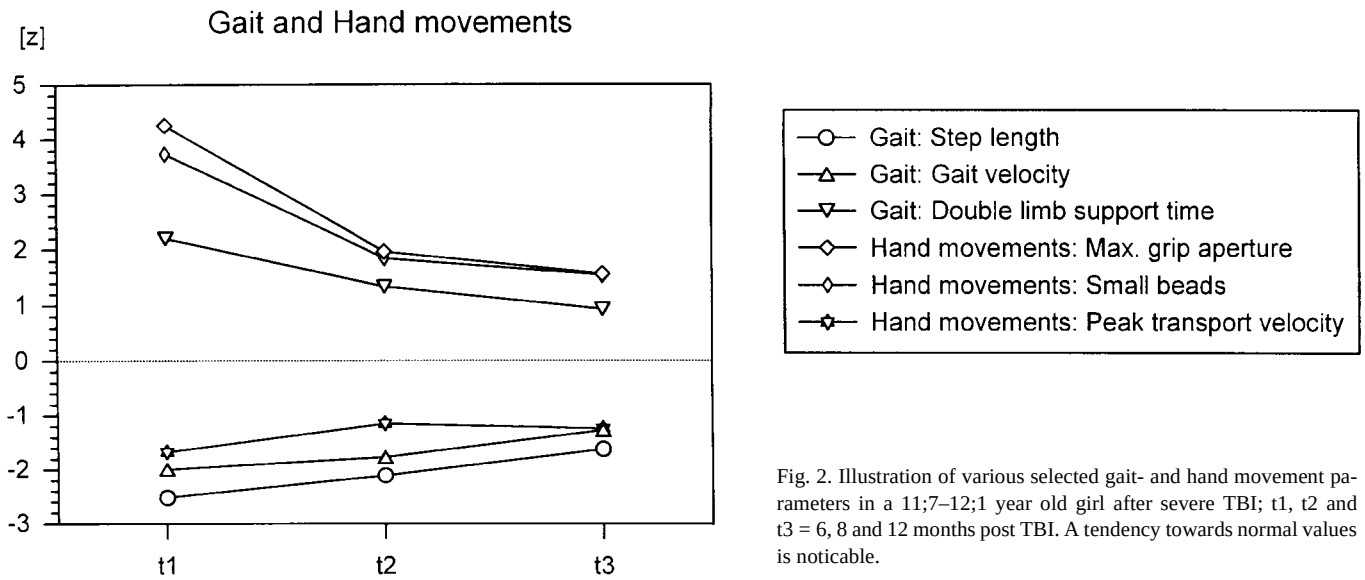

Fig. 2. Illustration of various selected gait- and hand movement parameters in a 11;7–12;1 year old girl after severe TBI; t1, t2 and t3 = 6, 8 and 12 months post TBI. A tendency towards normal values is noticable.

3.1.2. Clinical scores

Barthel-Index 100 (independent), Terver Score 12 (moderately impaired) and Rappaport Disability Rating Scale 4 (moderate grade of disability).

In this early phase of rehabilitation KTK could not be performed, because of severe ataxia.

In the *Motor Function Score* she reached a total value of 115 (of 207).

The *gait analysis* showed a distinct reduction of step- and stride length as well as gait velocity and duration of swing phase. Cadence did not change. As expected, we found an increase in step width, double limb support time and stance phase duration. The swing phase was shortened. There was no considerable change in gait cycle time.

Hand movement patterns showed an increase of movement initiation time and movement duration. A longer time interval was necessary to reach the maximum transport velocity. Peak transport velocity was decreased. We found a considerable increase of the maximum grip aperture. Both, small and large beads were threaded much more slowly than in healthy controls.

3.2. Second investigation (t2)

The *neurological status* was not essentially improved.

There were no changes in the *clinical scores*. The girl was still not able to perform *KTK*.

In the *Motor Function Score* Louisa showed an improvement of 22 raw-values.

All parameters of *gait analysis* and *hand movements* except cadence, foot angles, duration of deceleration and relative time to peak velocity showed a tendency towards normal values (Table 1, Fig. 1). The nearly constant relative time to peak velocity during prehension is due to the clear decrease of movement duration in comparison to the smaller reduction of the absolute time to peak velocity. The persistent decrease in the duration of deceleration seems to be a personal feature of this case which we have not yet seen in other patients after TBI.

3.3. Third investigation (t3)

Neurological findings. Generally unchanged moderately spastic tetraparesis, as mentioned above. However, no hypotonia of the trunk was noticeable and she showed a considerable improvement of her ataxia. Moreover she had achieved a higher degree of vigilance.

Except for a slight increase of the Numeric Score For Functional Assesment (Terver), as before, there were no changes in the *clinical scores.*

KTK could now be performed. She reached a MQ of < 40 according to a percentile of 0 in comparison to normal data of healthy children. These findings correspond to a MQ of 71 and a percentile of 3 compared to KTK data given for brain damaged children.

A further improvement of 12 raw values was shown in the *Motor Function Score* which was due to a higher degree of stability in various positions and improved movement transitions.

In all *spatial gait parameters* and in two *temporal gait parameters* (gait velocity and double limb support time) we noticed an ongoing trend to normalization (increase in step- and stride length and gait velocity, decrease in step width, foot angles and double limb support time).

Concerning *hand movements* there were no further essential improvements, except of the further decrease in the max. grip aperture.

3.4. Comparison between Overground- and Treadmill-Locomotion

In Table 3 gait parameters evaluated by both methods are presented. Normal values of two healthy groups (6 year old children (n = 16) and adults (n = 16)) [30] are shown. During all three investigations 17 of 21 differences were equal or higher than in both control groups. In all parameters (except swing phase during the third investigation) the direction of the changes was the same as in the controls. Compared to overground locomotion the stride length is

TABLE 3. Comparison of gait parameters evaluated by overground locomotion (OG) and by treadmill locomotion (TL). Means and % differences between OG and TL of a patient; examinations t1, t2 and t3 = 6, 8 and 12 months post severe TBI. Norm values for two control groups (6 year old children (N = 16), adults (N = 16)).

		t1			*t2*			*t3*			*Norm 6Yrs*	*Norm Adults*
		OG	*TM*	*%Diff*	*OG*	*TM*	*%Diff*	*OG*	*TM*	*%Diff*	*%Diff*	*%Diff*
Gait velocity	[m/s]	3.36	3.4		3.51	3.4		3.84	3.4			
Stride length	[cm]	100.86	91.9	– 9	107.79	91.8	–15	115.46	103.0	–11	– 7	– 4
Step width	[cm]	10.31	15.6	51	10.29	14.8	44	9.29	13.9	50	23	22
Foot angle	[°]	13.60	20.7	52	16.78	22.1	32	10.79	15.3	42	38	19
Cadence	[steps/min]	110.54	121.5	10	108.1	122.5	13	98.16	108.9	11	10	6
Stance phase	[ms]	743.1	634.4	–15	718.8	633.3	–12	743.7	703.9	– 5	–12	– 7
DLST	[ms]	192.7	141.1	–27	173.1	144.3	–17	164.5	153.5	– 7	–30	–27
Swing phase	[ms]	360.0	354.6	– 1	371.0	347.6	– 6	344.4	397.1	15	0	5
Mean (abs(diff%))				24			20			20	17.14	12.86

decreased and step width is clearly increased on the treadmill, both more pronounced in the patient than in the normal groups. Foot angle, cadence, stance- and swing phase were changed to the same degree as in the controls. The double limb support time was the only parameter which changed less. Averaged absolute differences for each investigation (t1, t2, t3) were considerably higher than in controls (t1: patient 24 %, controls 17 %), but they decreased over time (t3 : 20 %).

4. Discussion

It is a key finding of this study that the different tests mirrored the restitution of function to different degrees. Throughout the whole course, the clinical scores like Barthel, Terver and Rappaport could not contribute to the documentation of the motor restitution, which was caused by a clear ceiling effect. On the other hand it could not be denied – and it was proved by the kinematic analysis, that the girl still suffered from considerable motor impairments. In this case the application of those scores may have given useful information in earlier phases of rehabilitation. So we have to notice, that even well established and valid clinical scores have to be applied very carefully in consideration of the underlying temporal course.

The Motor Function Score seemed to document the initial sensorimotor deficits and their improvements in consensus with the quantitative movement analyses. However this requires further validation [32].

In the KTK the girl never reached the first percentile indicating the severity of the movement disorder. Improvements of motor performance could not be revealed until the end of the first year of rehabilitation, which was caused by a floor effect. However, it has to be emphasized, that the KTK primary has not been developed to document the recovery after brain-damage, but to detect children with motor delays. On the other hand, norm values for brain-damaged children have been presented. However, obviously this developmental test is not very suitable for the documentation of motor recovery over the whole restitutional course, especially in early phases after severe TBI with pronounced motor impairments.

In the kinematic analysis generally all parameters were changed in comparison to healthy controls. The movement analysis showed two types of movement dysfunctions during locomotion and prehension, a general slowing of movement and compensatory movement changes. Regarding locomotion, gait velocity considerably decreased [29]. In the kinematic assessment of hand movements mainly speed-associated parameters were affected, like movement duration and peak transport velocity, in agreement with the results of Chaplin et al. [5]. This general slowing of locomotion and prehension after TBI supports the notion [1] that the monitoring of speed-associated movement parameters may be useful to follow the course of restitution of motor function during rehabilitation.

On the other hand, compensatory motor strategies were present in both modalities to overcome ataxia during locomotion and grasp. Accordingly balance-related parameters like step width, stance phase and double limb support time increased to enhance stability in walk. In prehension movements the increase in the maximum grip aperture leads to the same result, a more efficient grasp [17,36]. Additionally the quantitative movement analysis could document a clear overall improvement rate -especially during the first time interval [3,13], which is in distinct contrast to the clinical scores and the KTK mentioned above.

The difference in gait patterns between overground locomotion (OL) and treadmill locomotion (TL) indicates the need for a careful diagnostic use of TL in impaired children, especially after severe TBI. To our opinion, less sophisticated methods like the gait analysis according to Brinckmann [4] can give a more realistic representation of the current status since spontaneous gait is influenced less [30].

The reported case demonstrates the heterogeneity of sensorimotor disorders [34] seen even in one single case and may give a brief outlook to the demand for individualized rehabilitation programs. Those programs should correspond to identified sensorimotor deficits and the expected sequence and velocity of their functional restitution.

5. Conclusion

The assessment of sensorimotor deficits and their functional restitution in children is associated with problems of precision, standardization, validation and comparability on one hand and requirements of comprehensiveness, feasibility (technical equipment, required time, know-how), cost-benefit analysis and a close relationship to functionality on the other hand. Moreover diagnostic tools should be able to document the current status throughout the whole course of recovery [1,5,8,9,26,30,32,33,34,35]. Additionally stress and strain in the impaired children should be avoided to ensure an undisturbed continuity of rehabilitation.

An accurate neurological investigation will be the basis for complementary evaluations, but it requires a high level of knowledge. Furthermore a lack of comparability is deplorable. Both, clinical scores and developmental tests (KTK) can not document the whole restitutional course. Clinical scores are useful in early phases, whereas developmental tests reveal changes in later phases of the recovery, especially for the follow-up over the next years. Other comprehensive motor tests with special emphasis on functional aspects like the Bruininks-Oseretzky Test of Motor Proficiency BOTMP [5], the Gross Motor Function Measure GMFM [9,27] and the test performed in the current study may be useful to complement the methodological concepts.

Quantitative movement analyses on one hand achieve a high degree of validity and reliability [31]. They can document nearly the whole restitutional course and are able to re-

veal basic aspects of movement changes. Even slight tendencies in single items can be revealed and they may be the base for rehabilitative concepts. On the other hand, quantitative analyses can not include the whole motor repertoire. These methods focus on single motor tasks (hand movements) or basic movement patterns (gait) and they often require elaborate technical equipment which may not be advantageous especially in impaired children as was demonstrated by the comparison between overground- and treadmill locomotion. However, to our experience quantitative movement analyses seem to be a promising completion in the assessment of sensorimotor deficits under the condition of reasonable item-selection.

In summary it has to be pointed out, that even well established tests with sufficient validation have to be applicated in consideration of the underlying purpose and temporal course. Otherwise ceiling- or floor effects can disturb a sufficient evaluation. It was an important finding, that the responsiveness of different tests may depend on the extent of the posttraumatic time interval.

We conclude that a sufficient evaluation of sensorimotor functions after TBI in childhood needs an increase in procedural uniformity [26] on one hand, and the combination of various qualitative and quantitative methods on the other hand. To connect both claims, further research is necessary.

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