Objective Assessment of Children with Birth Injuries

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Abstract— **Gézengúz Foundation for Children with Birth Injuries uses the patented hemisphere-like tool, Huple, to improve the balance ability of children with disability. Attaching an integrated 3D orientation sensor, x-IMU to Huple makes possible the objective assessment of the actual movement control of the child sitting in it. This is an important feedback for the therapy. The paper describes in detail the tested movement pattern, the evaluation algorithm and the results of ten children.**

Keywords— **birth injury, children with disabilities, objective assessment of movement control, Huple.**

I. INTRODUCTION

The therapy of children with birth injuries is a *habilitation* process - they never possessed the abilities to be developed. (Only those can be *re*-habilitated who once had the ability that has been lost.) Every birth injury is unique [1]. The Gézengúz Foundation (established in 1990) provides early intervention and complex therapy for children with movement disorders. To aid the complex therapy for these children – and also to help healthy children improve their balance and coordination ability – a special therapeutic tool, Huple (Fig. 1) was developed and patented [2], [3], [4].

Fig. 1 Huple the hemisphere shaped medical device.

The hemisphere shaped tool helps instructors in playfully improving and assessing the balance ability of children. Sitting in Huple is a complex task requiring the coordinated control of the muscles of the trunk and around the pelvic grindle. This task in itself has beneficial effect. Nevertheless, this is boring for the children. Attaching a 3D accelerometer to Huple it can be used as a PC input peripheral. ***Children are motivated and sustained attention is possible when they control PC games by moving Huple [5].*** This helps the habilitation process and also makes the assessment more reliable. The tilt angle of Huple determines the *speed* of an object on the screen (tilt → speed). The target position of the object can be reached with different tilt angles. This is perfect for motivating children to sit into Huple but it would result in a low reproducibility during assessment. A measurement procedure is needed to objectively assess the actual state (balance and movement coordination ability) of children. This gives a feedback for the therapy thus making it more effective.

II. MATERIALS AND METHODS

The movement coordination of children is usually ranked by therapists based on human observation. The resolution and reproducibility of human observation is relatively low. However, therapists are able to take into account more information about the tested children than orientation sensors.

It is a sophisticated procedure to approximate human evaluation by sensors and algorithms. The following steps are needed:

– selecting a sensor and attaching it to Huple,
– detailed definition of an appropriate movement,
– selection of the variable characterizing the movement,
– definition of parameters as well as algorithms that calculate the parameter values,
– calibration of algorithms based on measurement results taken from children whose movement coordination has been qualified and quantified by therapists,
– verification of the assessment method by applying it to another group of children.

A. The Sensor Hardware

The x-IMU has three three-dimensional sensors: accelerometer, magnetometer and gyroscope. The full scale ranges can be programmed. The maximum values are: ±8 g, ±8.1 G and ±2000 °/s. The resolution is 12 bit (16 bit for the

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gyroscope), the sampling frequency was set to 64 Hz (maximum 512 Hz). The device is small, with plastic housing and battery its size is 57 × 38 × 21 mm and it weighs 49 grams. Bluetooth communication is used with the PC. The device has two operating modes. We used the AHRS mode (Attitude Heading Reference System) which integrates the output of all three sensors. Further details are given in [6].

Fig. 2 demonstrates the difference between the integrated sensor x-IMU and a simple 3D accelerometer. The two sensors were attached to a stick. The stick was tilted in the x-y plane by 60°. In static positions, at the beginning and at the end of the experiment there is no substantial difference between the two sensor outputs. On the contrary, during the movement the integrated sensor outperforms the simple accelerometer in determining spatial orientation. Using a model that takes into account both the tangential and the centripetal acceleration would improve the performance of the simple accelerometer. However, the ***extra information provided by the gyroscope and the magnetometer*** would still make x-IMU more accurate in orientation measurement.

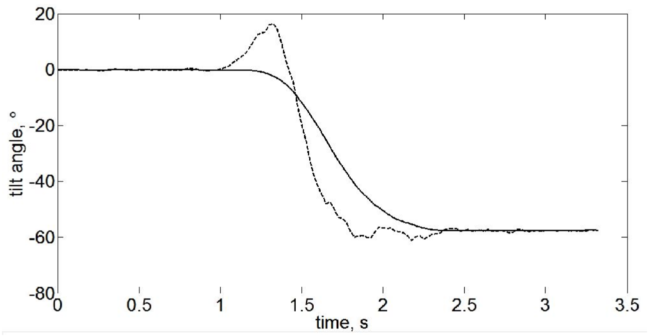

Fig. 2 The orientation measured by x-IMU (solid line) and by a 3D acceleration sensor (dashed line) during 60° tilting.

We did not want to attach markers or sensors to the children. One x-IMU sensor was attached to Huple. A single sensor gives an integral characterization of the child's movement that is an effective feature extraction. Of course, one sensor does not make it possible to characterize separately the movement of the child's body parts (limbs, trunk, head).

B. The Tested Movement: Active Tilting

For objective assessment of movement coordination the movement had to be defined in detail. Several movements were tried out where the tested child had to control the displacement of objects on the PC screen by maneuvering with Huple. Tasks requesting moving an object within a given zone on the screen were too difficult for some children. Seeing the deviation of the object from the specified zone they lost their interest in completing the test. This could have resulted in worse results than they could have reached. Thus, for more accurate assessment we changed the control algorithm. The position of the hand on the screen (see Fig. 3) is determined by the tilting angle of Huple in the frontal plane (tilt → position). This results in a good reproducibility regarding the tested movement. The hand on the screen does not have to be moved on a given trajectory, the only expectation is to tilt Huple by 30°.

The active tilting requires children to move Huple without any help. (Passive tilting: the therapist tilts Huple and then releases it. The return phase is assessed.) Children are requested to tilt Huple by 30° to the left or to the right, hold this position for 1.5 s and then move back to the initial position. Tilting forward and backward moves the hand up and down; tilting left and right moves the hand left and right. Tilting left-forward will result in a hand displacement into left-up direction, etc.

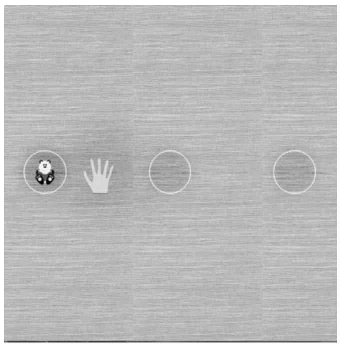

Fig. 3 The toy (bear) should be grabbed by the hand and then moved to the middle circle.

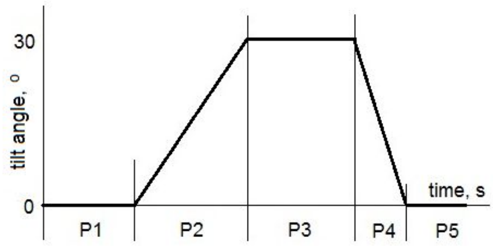

Fig. 4 Five phases of the tested movement. P1, P5: initial position, P2: 0° → 30°, P3: hold phase (min. 1.5 s), P4: 30° → 0°.

At the beginning of the test the child is asked to sit still and the PC program sets the related hand position to be in the middle of the screen (middle white circle in Fig. 3). 30° tilting to the left (to the right) moves the hand to the left (to the right) circle. The hand must be held for 1.5 s within the left (right) circle to grab the toy (it is a bear in Fig. 3) inside the circle. ±3° difference does not move the hand out of the circle. Finally the hand (in this phase holding the toy) must be moved back to the starting position. ***The movement is composed of five phases, see Fig. 4.***

C. Tested Children

We tested the active tilting movement of children participating in a therapy to improve their movement coordination. A therapist and a parent were always present during the tests, parents gave their written consent. Children C1 - C5 /Table 1 group (a)/ were tested several times in a six-week period. ***These recordings were used to develop algorithms which quantitate movement coordination based on the active tilting test.*** Details of the algorithms are given in the next paragraph. Algorithm development required the close cooperation of engineers and therapists. Based on visual observation therapists rated the tested children's movement coordination preceding the test using Huple. The ratings /10: best, 1: worst/ are given in the last column of Table 1 group (a).

The algorithms quantitating movement coordination were validated with tests performed by another group of children /C8 – C12, Table 1 group (b)/. Therapists qualified also children C8 – C12 preceding the active tilting test. Therapists could form only three categories /last column of Table 1 group (b)/ in this group: the best /C8/, the worst /C11/ and those in between /C9, C10, C12/.

Table 1 Children participating in the test

Patient	Gender	Age	Diagnosis	Rating by therapists
C1	female	5	central hypotonia	7/10
C2	female	3	benign congenital hypotonia	6/10
C3	female	3	benign congenital hypotonia	5/10
C4	male	4	minimal cerebral dysfunction	4/10
C5	female	3	myotonia congenita	3/10
			group (a)	
C8	male	8	motor and mental retardation, coordination problems	best
C9	male	5	pes planus, calcaneovalgus	middle
C10	male	6	congenital hypotonia, coordination problems	middle
C11	female	5	congenital hypotonia	worst
C12	male	6	minimal cerebral dysfunction	middle
			group (b)	

III. Evaluation of the Movement

The active tilting test is a game requiring well defined moving of Huple. It is appropriate for the assessment of the movement coordination of children.

The actual position of Huple determines its tilting angle in the anterior – posterior /AP, sagittal/ and in the medial – lateral /ML, frontal/ plane. Vice versa these two angles determine the position of Huple if it is not rotating around the longitudinal axis. If the child could sit completely still in Huple without the slightest movement then the tilting angle both in the AP and in the ML plane would be zero. Fig. 5. shows the movement of Huple for two children who were asked to sit still. This is the instruction in phases P1 and P5 of the active tilting test, see Fig. 4. For these phases it is a good approximation that Huple does not rotate around the longitudinal axis.

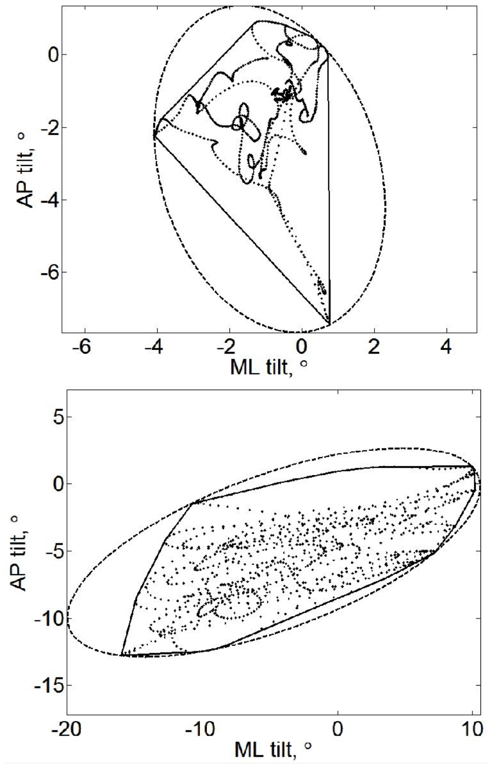

Fig. 5 Movement of Huple while the child is asked to sit still in it. AP: anterior-posterior, ML: medial-lateral.

In Fig. 5. the dotted lines show the actual movement of Huple. The smaller are the AP and ML tilt angles the closer is Huple to complete standstill. In P1 and P5 phases the performance is the better the smaller are the changes in tilt angles. The deviation of the tilt angles from an initial value is a good measure of the ability to sit still. ***This deviation can be characterized based on the area A_{cover} covering the dotted lines.*** In both subfigures of Fig. 5. the dashed line shows the ellipse with the smallest covering area and the solid line shows the convex polygon with the smallest covering area. However, one abrupt movement (see upper subfigure) substantially increases the area A_{cover}. It must be taken into account otherwise it would distort the score.

For the evaluation and quantification of the tested movement ***in phases P2 and P4 we used the time functions of the Euler angles of the x-IMU*** attached to Huple. In the initial position the three orientation angles (phi, theta, psi) are set to 0°. In the ideal case theta and phi would remain zero during the whole movement. Huple would be tilted only in the ML plane /left-right/ and tilting would remain zero both in the AP /forward-backward/ and in the longitudinal plane. A real recording is given in Fig. 6. It shows that the tested child moved the Huple not only left-right but slightly also forward-backward and even rotated it.

The following parameters were defined to characterize the movement coordination during the active tilting test:

(a) time to complete the test, also broken down to phases P2, P3 and P4,
(b) maximum speed in phases P2 and P4,
(c) average speed in phases P2 and P4,
(d) area A_{cover},
(e) dominant frequency component in phases P1 and P3,
(f) ratio t_c/t_{all} in phases P2 and P4, where t_c is the total time when the displacement of Huple is toward the requested target position and t_{all} is the total time of the given phase. The displacement is determined as the vector pointing from position (n-1) /P_{n-1}/ to position (n) /P_n/. The target position is P_T. If the distance (P_n, P_T) is smaller than the distance (P_{n-1}, P_T) then t_c is increased by t_s, the sampling time equal to 1/64 s.

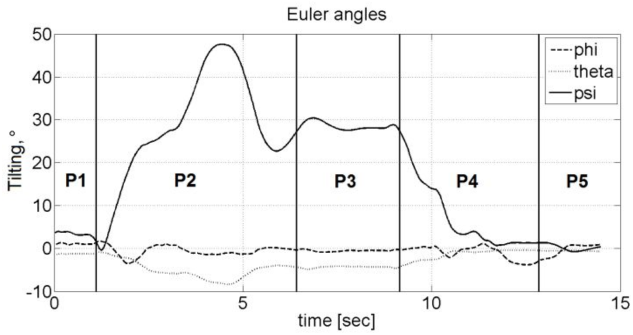

Fig. 6 Time functions of Euler angles of Huple during P1-P5 phases of the tested movement /performed by C1/.

(a), (b) and (c) showed high variance even for the same child. Furthermore, the maximum speed not necessarily belongs to intended movement – it rather happens as a result of an accidental abrupt movement. The area A_{cover} is suitable to characterize phases P1, P3 and P5 but fails during the more important phases P2 and P4. The dominant frequency shows high variance only for the best performing child. For the others this frequency is quite stable but does not characterize the movement coordination ability. ***The ratio of t_c/t_{all} harmonizes best with the ranking of therapists.*** Fig. 7 shows the results of five children. Within group (a) /C1 – C5/ the serial number reflects therapists' initial ranking, C1 best and C5 worst. Based on the active tilting test results, C5 performs better than C4. ***Therapists agreed with this modified ranking.*** C4 is different from all others in the group: the variance of his performance is extremely small.

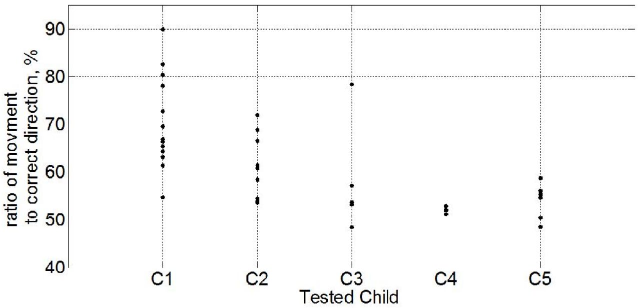

Fig. 7 Results of children C1 – C5. They were tested several times in a six-week period. The vertical value of a point is the average of t_c/t_{all} ratios in phases P2 and P4.

To verify the assessment method another group of children (group (b), C8 – C12) were tested half a year later than the first group. Fig. 8 shows their results in 2D: t_c/t_{all} ratios separately in phases P2 and P4. The results show high correlation with the therapists' ranking: C8 best, C11 worst, C9, C10, C12 middle.

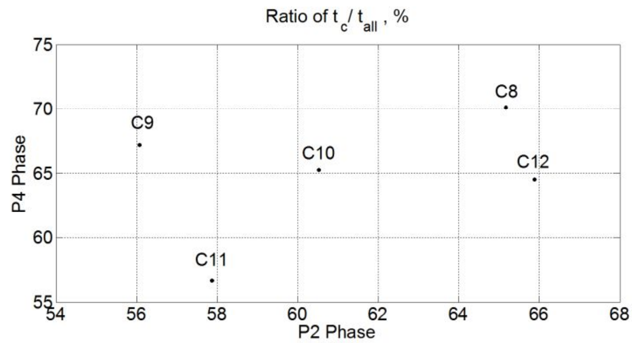

Fig. 8 Results of C8 – C12.

IV. CONCLUSIONS

The medical device Huple is applicable to assess the actual movement coordination of children with sensorimotor problems. This is a good feedback for their therapy thus making it more effective. The evaluation method based on x-IMU as an orientation sensor can easily be used by the therapists.

ACKNOWLEDGMENT

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