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Neural correlates of motor abilities in 6 year old children born very preterm

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Abstract

Children born very preterm are at risk of neurodevelopmental disabilities, among them developmental coordination disorders (DCD). The aim of this study was to evaluate the association of motor scores obtained through a validated and standardized test, and brain metrics, in a cohort of very preterm infants assessed at the age of 6 years. Our study includes 29 children born between 2001 and 2003 at the University Hospital of Lausanne. Neonatal data, clinical motor development test results, and neuro-imaging data were collected. The following neonatal data were correlated to development scores: sex, birthweight, in utero growth restriction and multiple pregnancy. There was mainly a strong and significant association of cortical thickness in the orbital and frontal lobes with adaptive motor tasks. Frontal lobe is involved in the executive control of behaviour with premotor areas. Occipital lobe includes several areas responsible for visual functions. Regression analysis showed no significant association of segmentation or cortical areas with motor scores. In conclusion these preliminary results suggest that there is an association between visual processing and motor development, and that early intervention on this could be considered in the management of development coordination disorder.

Introduction

Children born before term are at high risk of long-lasting neurodevelopmental problems including behavioural (1), cognitive (2) problems, academic difficulties (3) and motor problems, ranging from mild motor impairments such as developmental coordination disorders to cerebral palsy (4). These developmental issues affect preterm children with a frequency inversely correlated to gestational age, that is, the more preterm children are, the more severely they are affected by these neurodevelopmental sequelae.

DCD is a motor disability, which interferes with daily activities and social life. It affects around 6% of children in the general population(5), but the prevalence drastically increases, up to around 60% according to the existing literature, in extremely low birthweight children (6) (7) (8). This disorder may have different consequences, such as obesity due to the lower participation of the child in physical activity(9), lower academic achievement, social isolation, low self-esteem with anxiety or depression (10). When the diagnosis of DCD is suspected on the basis of the history, the primary care physician can use the “Developmental Coordination Disorder Questionnaire” a standardized questionnaire (11). To confirm the diagnoses, the gold standard is a result less than the fifth percentile on the Movement Assessment Battery for Children(12).

In Switzerland, children born before 32 weeks of gestation are offered standardized neurodevelopmental follow-up to the age of five years (13)(14). The last examination encompasses a thorough neurological examination and a standardized examination of motor function using the Zürich Neuromotorik Assessment (ZNM) (15).

Different risk factors for DCD have been identified in the literature: low gestational age, late age at walking, in utero growth restriction, low socioeconomic status, (16), chronic lung disease, intraventricular haemorrhage (17), multiple birth, periventricular leucomalacy, and intraventricular haemorrhage.(18)

Latal and al. studied the motor performance of very low birth weight children at six years using the ZNM (18). All timed components were lower in VLBW children. They also concluded that the motor performance was worse with increasing neurological abnormalities.

A rising body of literature aims at describing the neural correlates of neurodevelopment in preterm infants, with magnetic resonance imaging (MRI) either at term equivalent age, or later in childhood, adolescence or even adulthood. There is an evidence that abnormal white matter seen on neonatal brain MRI is associated with adverse neurodevelopmental outcomes (cognitive delay, motor delay, cerebral palsy, neurosensory impairment)(19), although the predictive validity remains low except for cerebral palsy (20). Recently, Ullmann et all described significant correlations between neonatal brain volumetric measures in very preterm infants and childhood measures of mathematics and executive functions (21)

Other researches about neuroimaging and developmental coordination disorder more specifically have been performed. The results are nevertheless controversial. Four studies showed that children with DCD at school age activate different areas of their brain than controls. According to a review by Peters et al, on neuroimaging studies and DCD (22), three studies confirm an association between white matter abnormalities or severe MRI abnormalities and DCD (23). Nevertheless, four others did not show this relationship. The data about neuroimaging and DCD is thus scarce and disputed.

Adequate motor function implies the integrity of different regions of the brain. First, the central nervous system needs sensory inputs, on the position, velocity and acceleration of the limb. The target of the movement is situated in space, which implicates the visual system, as well as proprioceptive and tactile information. The primary motor cortex is of course implicated, as well as the basal ganglia, and the parietal cortex which plays a role in integration.

The aim of our study was thus to study at the age of 5 years the correlation of brain volumetric measurements with motor abilities assessed with the ZNM, in a cohort of children born very preterm.

Method

Design

This study was nested in a prospective cohort study of the relationship between preterm child development and the neurostructure of brain.

Population

During the study period between the 01.01.2001 and the 31.12.2003, 103 infants were born before 29 weeks in our tertiary care neonatal centre, 29 of which died in the neonatal period, 16 refused participation and 23 were excluded (5 severe developmental delays, 3 moved out of the country, 5 families who did not speak the language, 3 out of range time frame, 2 social

issues, 2 families with severe social issues, and 3 families which could not be reached). Among the 36 remaining children assessed at 6 years old, 7 had to be excluded from the analysis because of absent imaging. The participants were thus twenty-nine very preterm infants for whom the datasets on cognitive, motor and imaging examinations were complete. Inclusion criteria were gestational age less than 29 weeks, absence of major brain lesions on brain ultrasound(24), absence of genetic abnormalities known to interfere with development.

Written informed consent was obtained after written and oral information about the aims and procedure of the study had been given.

Information about the following neonatal variables, were collected: sex, birthweight, gestational age in completed weeks of gestation, multiple pregnancy, in utero growth restriction defined by birthweight <5th percentile for gestational age, socioeconomic status assessed with Largo score (25), proven necrotizing enterocolitis, asphyxia defined by umbilical artery pH < 7, proven sepsis with positive blood cultures.
All the participants had a comprehensive neurodevelopmental assessment at the age of 6 years, with a detailed neurological examination to rule out the diagnosis of cerebral palsy, and vision and hearing tests. Cognition was assessed with the French edition of Kaufmann Assessment Battery for Children (K-ABC) (26).
The 29 children included in this study underwent Magnetic Resonance Imaging at 6 years of age. All MRI scanning were performed with a 3 Tesla MR system. Diffusion-weighted Imaging was acquired with a spin-echo EPI sequence with 6 gradient directions. Volumetric measurements were obtained through standard image sequences (double-echo, spin echo, coronal slices of the whole brain and 3D Fast-Gradient-recalled acquisitions in the coronal plane). We collected the imaging data, which consisted in different data: the segmentation data, the cortical areas and the cortical thickness of several cerebral regions.

Outcomes

To evaluate motor abilities, the Zürcher Neuromotorik Assessment was used. The ZNMA is a standardized, reliable test which appraises different motor abilities(15). Several motor tasks are assessed in the test. The purely motor tasks consist in repetitive movements of the fingers, the hand and the foot, alternating movements of hand and foot, and sequential finger movements. The adaptive tasks are evaluated through the pegboard and the dynamic balance. Static balance and posture are assessed as well. The results of the test are z-scores, which can be compared with normal values, provided for children from 5 to 18 years. Furthermore, the test allows the quantification of involuntary associated movements.
The five z-scores of the test results, purely motor, adaptive pegboard, adaptive dynamic balance, balance and associated movements were outcomes of this study.

Statistics

Neonatal and outcome data were reported with means (standard deviations) for continuous data and frequencies (%) for categorical data. The associations between the 5 z-scores of the ZNM and the clinical data first, and structural brain measures were analysed with linear regressions. Then we grouped the brain volumes variables by brain region, and observed which brain area, thickness, segmentation or neonatal variable were significatively correlated to the development indicators (ZNMA scores and quality of movement). The association was considered significant when the p value was smaller than 0.05.

Results

Population characteristics

Our sample of 29 children born very preterm included 16 males and 13 females. Neonatal and follow-up characteristics, including summary results of motor scores, are reported in table 1. There was a shift to the left of the distribution of motor z-scores, in relation with poorer motor abilities of preterm children, even without major brain lesions.

Table 1: population characteristics

	N=29
Neonatal variables	
Boys/girls	16/13
Birthweight (g, mean, SD))	882.4 (231, 510-1320)
Gestational age (weeks, days)	26 5/7 (7 days)
IUGR	8 (27 %)
Multiple pregnancy	6 (21 %)
Largo score	6.3 (2.4, 2-11)
Proven sepsis	6 (21%)
Necrotising enterocolitis	1 (0.03 %)
BPD	12 (41.3%)
Follow-up variables	
Age at assessment (months, mean, range)	67.8 (62-79)
Left handedness (n, %)	5 (17.2%)
Age at walking (corrected, months, mean, SD)	14.5 (2.3, 10-18.5)
Composite mental processes K-ABC (mean, SD)	93.8 (13.1)
ZNMA motor z-score(mean, SD)	-0.58 (1.53,-4.3 - +2.5)
ZNMA adaptative pegboard z-score(mean, SD)	-2.13 (1.21, -4.4- +0.2)
ZNMA adaptative dynamic balance z-score(mean, SD)	-1.21(1.02, -3.3-+0.7)
ZNMA balance z-score(mean,SD)	-0.41(1.14, -3.6-+1.9)
ZNMA associated movements z-score (mean,SD)	-0.74 (1.10, -2.5- +2.6)

Correlation between clinical variables and motor scores

Neonatal determinants

The association between neonatal variables known from the literature to have an impact on motor abilities was explored with linear regression. Several neonatal determinants were correlated to ZNMA adaptive pegboard scores: Sex, with girls obtaining better scores than boys (p=0.0107, coeff. =1.3, CI= (0.33; 2.27)), birthweight (p=0.0033, coeff. =0.003, CI= (0.001; 0.005)), IUGR (p= 0.0425, coeff. = -0.76, CI= (-1.5; -0.28)), and bronchopulmonary dysplasia (p=0.01, coeff. = -0.22, CI= (-0.38; -0.06)).

Sex was also associated with ZNMA dynamic balance (p=0.0177, coeff= 1.15, CI= (0.22; 2.09)), still with girls obtaining better scores.

Birthweight (p=0.01, coeff= 0.003, CI= (0.0006; 0.005)) as well as IUGR (p= 0.002, coeff. = -1.02, CI= (-1.6; 0.43)), was significantly associated with ZNMA balance.
There was no association of sepsis or gestational age with the 5 motor variables.

Correlation between cortical areas and motor scores

The correlation coefficients between the 68 cortical brain areas and the 5 motor scores were close to zero, showing no effect of cortical area on motor abilities.

Correlation between cortical segmentation (volumes) and motor scores

Similarly, the correlation coefficients between the brain volumes were all close to zero.

Correlation between cortical thickness and motor scores

In table 2 (annex) we show the regression analysis of cortical thickness with the 5 motor scores. The purely motor score was negatively associated with cortical thickness in the frontal lobe (inferior and superior gyri), and the occipital lobe (cuneus, pericalcarine and lateral occipital gyri).

The adaptative pegboard task was significantly associated with cortical thickness in the frontal (middle and superior frontal gyri, and orbito-frontal gyrus) as well as with all the analyzed regions of the occipital lobe. The post central parietal gyrus was also significantly and negatively associated with this task.

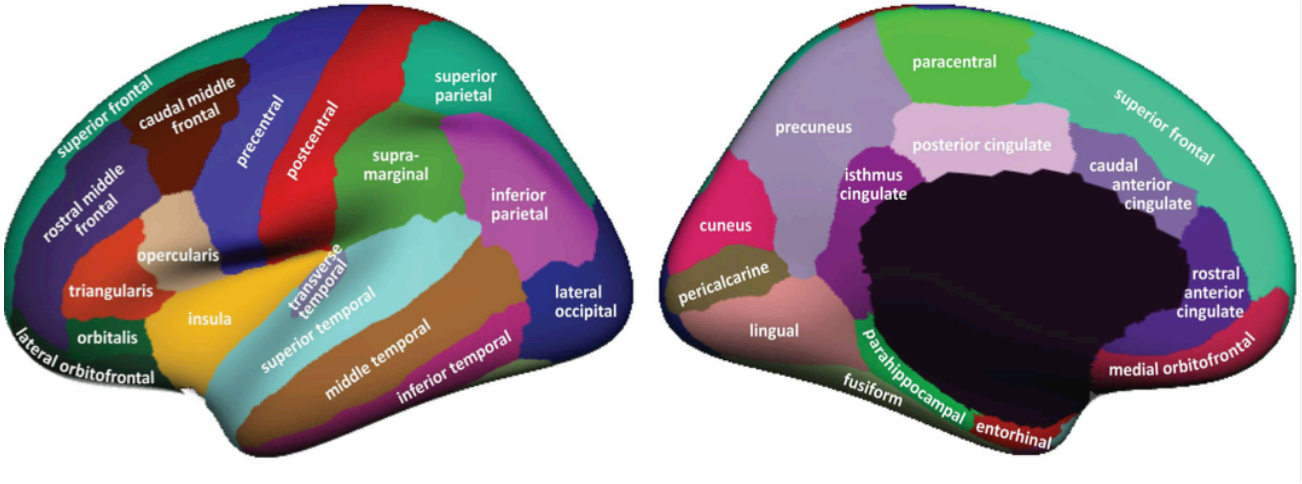
The adaptative dynamic balance task was mainly associated with the occipital lobe (cuneus, pericalcarine and lingual gyri), and with the pars opercularis of the inferior frontal gyrus.

The purely static balance task was significantly associated with one frontal gyrus (pars orbitalis), and one occipital gyrus (lingual area).

Finally there was no association of movement quality with any of the cortical measures.

The different cerebral areas are represented in figure 1 (27).

Figure 1: cerebral areas (27)



Discussion

Neonatal determinants of motor abilities

Results showed that sex, birthweight, in utero growth restriction and multiple pregnancies were associated with motor abilities.

Sex was correlated to ZNMA adaptive pegboard and dynamic balance tasks, with girls having better scores than boys.

There is a controverse in the literature about whether male sex is associated to poorer motor development in children born preterm. Latal and al. found no relation between sex and motor development, but other studies like F. Larsen and al. found significant differences between males and females in motor scores.

Birthweight was correlated to ZNMA adaptive pegboard and balance, and to age at walking. This is consistent with the other studies in the literature(16)

In utero growth restriction was strongly associated with ZNMA adaptive pegboard and balance scores, and with age at walking, as it has already been shown in other studies (18).

Multiple pregnancy had a negative association with age at walking, as well as with the quality of the movements, measured by associated movements. This result is consistent with the existing literature. Indeed, Latal and al. showed that multiple birth status was related to poorer performance but in their case on the pure motor component.
Our results show that multiple pregnancy influences negatively the associated movement. Due to the sample size, we used univariate analysis. We could therefore not exclude bias due to multiple pregnancy leading to smaller birthweight or more complicated pregnancies.

Neural correlates of motor abilities

The analysis of the correlation between brain metrics and motor scores in preterm children showed several significant results. First, all the regression coefficients were negative, thus implying a negative association between cortical thickness and motor abilities This is in agreement with the known maturation of brain, associated with cortical thinning due to pruning.
Most of the significant results concerned the adaptive tasks, pegboard and dynamic balance. There was no significant association regarding balance or associated movements. Our population was a healthy cohort of preterm children, without brain injury, but our MRI protocol did not include cerebellar measures which could have contributed to these last measures.

Frontal lobe

There were several significant associations of cortical thickness with motor abilities, notably purely motor such as hand or foot tapping, and difficult fine motor task. The frontal lobe is involved in the executive control of behaviour, with the premotor areas, which is connected to the dorsolateral prefrontal cortex, and then the orbital-ventromedial prefrontal cortex. An fMRI study has shown that adults born very preterm have decreased grey matter volume in the premotor cortex (28), which could explain the frequent motor coordination difficulties in this population.

Visual areas

Occipital lobe: There was a strong and significant association of bilateral occipital cortical thicknesses (cuneus , pericalcarine, lingual, precuneus and lateraloccipital)with several motor subtests, the purely motor, and the 2 adaptive tests.
Sensory inputs about the position, velocity and acceleration of the limb are necessary for precise movements. Somatosensory cortex is connected to the primary motor cortex (Brodmann 4) and the precentral motor area (Brodmann 6) in order to transfer these sensory informations(29).

Parietal lobe: There was a significant association between superior and post-central parietal cortex and the adaptive pegboard. These regions are involved in the integration of visual information, in the processing of peripersonal space. The ventral visual stream (« where » pathway) and the dorsal (« what » pathway) visual stream are situated in the parietal lobe.

Temporal lobe

Neurons in the middle temporal area, as well as in the medial superior temporal areas calculate the velocity of the visual target. Our results show that the right and left superior temporal cortical thicknesses are significantly correlated to the ZNMA adaptive pegboard score.

Basal ganglia

In the segmentation measures (table 2), basal ganglia (caudate and pallidum) were significantly associated with ZNMA adaptive pegboard score, but the coefficients were nearly zero, so the clinical effect was negligible. We had expected a more significant result for basal ganglia, composed of the the striatum, the pallidum, the substancia nigra and the subthalamic nucleus.

The four circuits that originate in the frontal cortex projects to the basal ganglia and finally the motor cortex, supplementary motor area, and premotor cortex. The motor circuits of basal ganglia are associated with action selection, movement planning and execution, sequencing of movement, self-initiated or remembered movements, control of movement parameters, and reinforcement learning.(29)

Dysfunction of the basal ganglia may lead to severe movement disorders, which were excluded in our preterm cohort, without motor deficiency. Z-scores were in the normal range although between -0.41 and -2.31 lower than the standardized test.

In summary, the motor abilities of preterm children, even without motor deficiencies, are associated with specific cortical maturational processes. The more discriminating adaptive motor tasks show the involvement of mainly visual areas, but also frontal (motor), parietal and temporal areas. Future research should compare the implications of all these regions in healthy term controls, and evaluate the effect of maturation, so as to discriminate between delay and disability.

The limitations of this study are the small sample size and lack of control group, which does not allow the use of multivariate analysis and the controlling of potential confounders.

Conclusion

Our results are preliminary in the field of imaging and motor development; it is primordial to pursue the research in this subject. DCD are a common affection of preterm children, and rate of children born preterm is considerable. Studies based on these preliminary results would be useful, and early intervention based on visual processing should be evaluated.

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	Purely motor			Adaptative pegboard			Adaptative dynamic balance			Balance			Quality		
	Coeff	95% Conf. Interv.	p value	Coeff	95% Conf. Interv.	p value	Coeff	95% Conf. Interv.	p value	Coeff.	95% Conf. Interv.	p value	Coeff.	95% Conf. Interv.	p value
Frontal lobe															
Caudal middle frontal left cortical thickness	-4,87	-10,8; ; 1,14	0,107	-0,05	-3,71 ; 3,61	0,978	1,90	-1,43 ; 5,22	0,249	1,71	-1,60 ; 5,01	0,297	3,33	0,42 ; 6,24	0,027
Caudal middle frontal right cortical thickness	-4,79	-9,45 ; -0,13	**0,045**	-3,08	-6,31 ; 0,14	0,060	-0,79	-4,04 ; 2,46	0,619	-1,32	-4,46 ; 1,83	0,396	1,41	-1,60 ; 4,42	0,338
Pars triangularis left cortical thickness	-3,57	-6,77 : -0,38	**0,030**		-3,93 ; 1,48	*0,068*	-0,60	-2,66 ; 1,46	0,551	-1,23	-3,20 ; 0,74	0,209	1,37	-0,38 ; 3,12	0,119
Pars triangularis right cortical thickness	-3,84	-7,85 ; 0,17	0,060	-0,79	-3,84 ; 2,26	0,597	0,15	-2,72 ; 3,03	0,913	1,93	-0,77 ; 4,62	0,152	2,69	0,38 ; 4,99	0,025
Rostral middle frontal left cortical thickness	-2,77	-7,28 ; 1,73	*0,215*	-2,62	-5,50 ; 0,26	*0,073*	-1,24	-4,19 ; 1,71	0,394	1,73	-1,07 ; 4,53	0,215	0,66	-1,96 ; 3,28	0,606
Rostral middle frontal right cortical thickness	-3,30	-6,75 ; 0,15	*0,060*	-3,36	-5,67 ; -1,05	**0,006**	-1,47	-3,94 ; 1,00	0,230	1,56	-0,87 ; 3,99	0,198	0,79	-1,52 ; 3,10	0,485
Pars orbitalis left cortical thickness	-0,85	-3,47 ; 1,76	0,505	-0,67	-2,50 ; 1,16	0,456	0,23	-1,94 ; 2,31	0,825	0,76	-0,95 ; 2,48	0,366	0,51	-1,02 ; 2,05	0,493
Pars orbitalis right cortical thickness	-0,57	-2,71 ; 1,57	0,586	-0,61	-1,97 ; 0,75	0,363	0,57	-0,72 ; 1,85	0,370	1,39	0,26 ; 2,52	**0,018**	0,57	-0,61 ; 1,74	0,325
Frontal pole left cortical thickness	-1,20	-3,53 ; 1,13	0,297	-0,65	-2,26 ; 0,97	0,416	-0,20	-1,73 ; 1,33	0,789	0,69	-0,80 ; 2,17	0,348	0,92	-0,88 ; 2,73	0,297
Frontal pole right cortical thickness	-1,01	-3,19 ; 1,16	0,344	-0,63	-2,18 ; 0,91	0,405	-0,09	-1,56 ; 1,37	0,895	-0,28	-1,67 ; 1,12	0,684	0,85	-0,46 ; 2,17	0,191
Medial orbitofrontal left cortical thickness	-1,30	-3,76 ; 1,16	0,285	-2,05	-3,59 ; -0,52	**0,011**	-1,35	-2,90 ; 0,21	*0,087*	-0,24	-1,88 ; 1,40	0,769	0,45	-1,05 ; 1,96	0,535
Medial orbitofrontal right cortical thickness	-1,47	-3,56 ; 0,62	0,158	-1,59	-3,00 ; -0,18	**0,029**	-0,91	-2,32 ; 0,50	0,196	-0,78	-2,19 ; 0,63	0,267	0,50	-0,83 ; 1,82	0,444
Paracentral left cortical thickness	-0,74	-4,93 ; 3,45	0,716	-1,56	-4,42 ; 1,29	0,269	-0,88	-3,66 ; 1,91	0,521	-0,37	-3,13 ; 2,39	0,784	0,27	-2,69 ; 3,23	0,850
Paracentral right cortical thickness	-3,23	-7,87 ; 1,41	0,162	-1,25	-4,57 ; 2,06	0,442	-0,69	-3,81 ; 2,44	0,654	-1,11	-4,17 ; 1,95	0,462	1,80	-1,46 ; 5,05	0,263
Parsopercularis left cortical thickness	0,28	-4,55 ; 5,11	0,906	-1,90	-5,19 ; 1,39	0,244	1,39	-1,75 ; 4,54	0,367	1,67	-1,41 ; 4,74	0,274	1,20	-1,65 ; 4,04	0,391
Parsopercularis right cortical thickness	-4,26	-8,08 ; -0,44	**0,030**	-3,39	-6,10 ; -0,68	**0,016**	-3,00	-5,76 ; -0,25	**0,034**	1,07	-1,78 ; 3,92	0,446	-0,33	-3,25 ; 2,60	0,816
Pre central left cortical thickness	-1,84	-6,95 ; 3,27	0,462	-3,06	-6,55 ; 0,42	*0,082*	-0,72	-4,66 ; 3,23	0,709	2,25	-1,49 ; 6,00	0,226	2,67	-0,18 ; 5,53	
Pre central right cortical thickness	-1,56	-7,44 ; 4,31	0,586	-4,92	-8,31 ; -1,52	**0,007**	-2,49	-6,34 ; 1,35	0,193	0,26	-3,67 ; 4,20	0,891	1,28	-2,30 ; 4,87	0,464
Superior frontal left cortical thickness	-3,71	-7,39 ; -0,03	**0,048**	-1,81	-4,60 ; 0,98	**0,192**	-0,90	-3,70 ; 1,90	0,512	2,31	-0,24 ; 4,87	0,074	1,11	-1,38 ; 3,59	0,363
Superior frontal right cortical thickness	-4,78	-8,84 ; -0,72	**0,023**	-3,38	-6,39 ; -0,38	**0,029**	-2,26	-5,37 ; 0,84	0,145	0,10	-3,11 ; 3,31	0,949	1,54	-1,15 ; 4,22	0,246
Lateral orbitofrontal left cortical thickness	-2,88	-6,45 ; 0,69	0,108	-1,01	-3,34 ; 1,33	0,382	0,43	-1,82 ; 2,69	0,694	1,02	-1,13 ; 3,17	0,337	1,55	-0,29 ; 3,39	0,093
Lateral orbitofrontal right cortical thickness	-3,76	-7,04 ; -0,48	**0,027**	-3,38	-5,94 ; -1,64	**0,001**	-2,25	-4,57 ; 0,07	*0,057*	0,01	-2,48 ; 2,49	0,996	0,14	-2,29 ; 2,56	0,907
Parietal lobe															
Superior parietal left cortical thickness	-3,72	-7,60 ; 0,15	*0,059*	-2,56	-5,25 ; 0,13	*0,061*	-1,03	-3,71 ; 1,65	0,434	-0,48	-3,16 ; 2,19	0,712	0,71	-1,92 ; 3,34	0,578
Superior parietal right cortical thickness	-2,29	-5,26 ; 0,68	0,124	-2,12	-4,18 ; -0,06	**0,045**	-0,78	-2,87 ; 1,31	0,449	-0,11	-2,19 ; 1,97	0,915	0,56	-1,56 ; 2,68	0,588
Post central left cortical thickness	-0,86	-4,56 ; 2,85	0,636	-2,76	-5,16 ; -0,37	**0,026**	-1,07	-3,65 ; 1,52	0,401	-1,83	-3,27 ; 0,60	0,133	-0,18	-2,82 ; 2,46	0,886
Post central right cortical thickness	-1,03	-4,16 ; 2,09	0,498	-1,13	-3,32 ; 1,06	0,298	-0,58	-2,76 ; 1,60	9,587	-1,11	-3,19 ; 0,97	0,280	0,02	-2,25 ; 2,30	0,984
Supramarginal left cortical thickness	1,48	-3,34 ; 6,30	0,530	-2,45	-5,88 ; 0,98	0,153	1,17	-2,30 ; 4,64	0,492	1,50	-1,90 ; 4,89	0,372	0,16	-2,94 ; 3,26	0,917
Supramarginal right cortical thickness	-0,01	-5,85 ; 5,83	0,997	-2,43	-6,57 ; 1,71	0,237	-1,04	-4,90 ; 2,82	0,582	1,39	-2,40 ; 5,18	0,457	-1,54	-5,42 ; 2,34	0,416
Inferior parietal left cortical thickness	-2,28	-7,27 ; 2,70	0,351	-1,33	-4,93 ; 2,27	0,451	0,30	-3,09 ; 3,69	0,857	2,00	-1,23 ; 5,24	0,213	1,53	-1,54 ; 4,60	0,309
Inferior parietal right cortical thickness	-2,41	-6,06 ; 1,03	0,155	-2,81	-5,13 ; -0,41	0,024	-1,09	-3,66 ; 1,48	0,389	0,77	-1,71 ; 3,25	0,527	0,44	-2,09 ; 2,98	0,719

	Purely motor				Adaptative pegboard				Adaptative dynamic balance				Balance				Quality			
	Coeff	**95% Conf. Interv.**		**p value**	**Coeff**	**95% Conf. Interv.**		**p value**	**Coeff**	**95% Conf. Interv.**		**p value**	**Coeff**	**95% Conf. Interv.**		**p value**	**Coeff**	**95% Conf. Interv.**		**p value**
Temporal lobe																				
Middle temporal left cortical thickness	0,53	-5,27 ;	6,33	0,851	-1,54	-5,61 ;	2,53	0,442	1,36	-2,44 ;	5,17	0,466	1,81	-1,92 ;	5,53	0,326	1,77	-1,70 ;	5,23	0,299
Middle temporal right cortical thickness	-2,41	-6,31 ;	1,50	0,214	-2,79	-5,58 ;	0,00	*0,050*	0,39	-2,42 ;	3,21	0,775	-0,71	-3,47 ;	2,06	0,602	1,33	-1,60 ;	4,26	0,354
Transverse temporal left cortical thickness	-2,05	-6,74 ;	2,64	0,373	-1,71	-4,98 ;	1,55	0,289	-0,03	-2,99 ;	2,92	0,982	-2,98	-5,60 ;	-0,36	**0,028**	1,25	-1,63 ;	4,12	0,375
Transverse temporal right cortical thickness	-0,81	-4,81 ;	3,19	0,677	-0,44	-3,08 ;	2,19	0,730	0,32	-2,13 ;	2,78	0,788	-0,34	-2,75 ;	2,07	0,776	0,41	-1,90 ;	2,73	0,712
Fusiform left cortical thickness	-4,12	-10,0 ;	1,19	0,164	-5,26	-9,05 ;	-1,46	**0,009**	-2,52	-6,44 ;	1,39	0,195	-2,36	-6,15 ;	1,43	0,210	0,24	-3,62 ;	4,11	0,896
Fusiform right cortical thickness	-3,29	-8,78 ;	2,21	0,227	-1,52	-5,33 ;	2,28	0,416	-0,46	-4,00 ;	3,07	0,789	-0,53	-4,01 ;	2,95	0,757	2,60	-0,44 ;	5,64	0,090
Temporal pole left cortical thickness	-1,07	-2,67 ;	0,53	0,179	-1,02	-2,15 ;	0,12	*0,077*	-0,73	-1,82 ;	0,35	0,174	-0,25	-1,37 ;	0,86	0,643	0,41	-0,61 ;	1,43	0,414
Temporal pole right cortical thickness	0,12	-2,01 ;	2,26	0,906	-0,40	-1,89 ;	1,10	0,589	-0,12	-1,54 ;	1,30	0,864	-0,49	-1,88 ;	0,89	0,470	-0,13	-1,50 ;	1,24	0,843
Superior temporal left cortical thickness	-0,45	-6,94 ;	6,04	0,887	-4,86	-8,53 ;	-1,19	**0,012**	-0,79	-4,72 ;	3,16	0,684	0,84	-3,06 ;	4,73	0,661	0,00	-3,87 ;	3,88	0,999
Superior temporal right cortical thickness	-0,02	-5,20 ;	5,16	0,994	-4,48	-7,72 ;	-1,24	**0,009**	-0,16	-3,66 ;	3,34	0,925	-0,77	-4,21 ;	2,67	0,648	1,39	-2,61 ;	5,38	0,476
Entorhinal left cortical thickness	-0,31	-2,52 ;	1,90	0,776	-1,40	-2,95 ;	0,14	*0,073*	-0,40	-1,89 ;	1,10	0,585	0,21	-1,27 ;	1,69	0,773	0,96	-0,57 ;	2,49	0,205
Entorhinal right cortical thickness	-0,14	-2,18 ;	1,89	0,886	-1,23	-2,67 ;	0,21	*0,091*	-0,48	-1,86 ;	0,89	0,473	-0,49	-1,84 ;	0,87	0,464	0,01	-1,36 ;	1,39	0,985
Inferior temporal left cortical thickness	0,81	-4,01 ;	5,63	0,730	-2,46	-5,54 ;	0,61	0,111	0,16	-3,07 ;	3,39	0,920	0,88	-2,12 ;	3,89	0,549	0,80	-1,95 ;	3,54	0,549
Inferior temporal right cortical thickness	0,36	-4,33 ;	5,05	0,875	-1,91	-4,95 ;	1,13	0,206	0,12	-2,86 ;	3,11	0,932	-0,16	-3,07 ;	2,76	0,912	-0,13	-2,80 ;	2,55	0,922
Banksst left cortical thickness	0,15	-4,50 ;	4,81	0,946	0,00	-2,96 ;	2,97	0,998	2,13	-0,52 ;	4,78	0,110	1,59	-1,08 ;	4,24	0,229	0,41	-2,05 ;	2,87	0,729
Banksst right cortical thickness	-0,23	-4,22 ;	3,76	0,907	-0,09	-2,97 ;	2,80	0,951	1,28	-1,37 ;	3,93	0,326	0,99	-1,66 ;	3,63	0,448	1,70	-0,72 ;	4,12	0,159
Occipital lobe																				
Cuneus left cortical thickness	-3,98	-8,21 ;	0,25	*0,064*	-3,92	-6,47 ;	1,36	**0,004**	-3,41	-5,88 ;	-0,94	**0,009**	-0,87	-3,68 ;	1,93	0,525	0,13	-3,16 ;	3,41	0,936
Cuneus right cortical thickness	-5,13	-0,91 ;	-1,18	**0,013**	-3,95	-6,59 ;	-1,32	**0,005**	-4,47	-6,67 ;	-2,27	**0,000**	-1,60	-4,35 ;	1,16	0,242	-1,48	-4,22 ;	1,26	0,273
Pericalcarine left cortical thickness	-6,65	-10,4 ;	-2,91	**0,001**	-3,43	-6,26 ;	-0,59	**0,020**	-3,91	-6,40 ;	-1,41	**0,004**	-2,05	-4,90 ;	0,80	0,151	0,42	-2,29 ;	3,12	0,751
Pericalcarine right cortical thickness	-4,02	-9,27 ;	1,22	0,126	-3,37	-6,66 ;	-0,09	**0,045**	-4,11	-7,05 ;	-1,17	**0,008**	-1,21	-4,48 ;	2,05	0,450	-0,15	-3,72 ;	3,42	0,930
Lateral occipital left cortical thickness	-4,76	-9,01 ;	-0,51	**0,030**	-3,42	-6,57 ;	-0,28	**0,034**	-1,89	-5,01 ;	1,22	0,221	-1,86	-4,90 ;	1,19	0,220	-0,10	-3,32 ;	3,13	0,951
Lateral occipital right cortical thickness	-4,69	-8,88 ;	-0,50	**0,030**	-3,25	-6,35 ;	-0,16	**0,040**	-2,73	-5,61 ;	0,15	*0,062*	-1,92	-4,89 ;	1,06	0,195	-0,17	-3,11 ;	2,76	0,904
Lingual left cortical thickness	-0,98	-5,72 ;	3,77	0,673	-3,17	-5,82 ;	-0,52	**0,021**	-3,05	-5,43 ;	-0,67	**0,014**	-2,52	-4,95 ;	-0,09	0,043	-0,62	-3,13 ;	1,89	0,610
Lingual right cortical thickness	-3,90	-8,57 ;	0,75	0,096	-3,18	-6,24 ;	-0,12	**0,042**	-3,35	-6,11 ;	-0,60	**0,019**	-3,93	-6,50 ;	-1,37	**0,004**	-0,61	-3,76 ;	2,54	0,689
Precuneus left cortical thickness	-3,50	-8,54 ;	1,55	0,164	-4,16	-7,44 ;	-0,88	**0,015**	-2,20	-5,56 ;	1,16	0,188	-0,33	-3,77 ;	3,12	0,846	-1,80	-5,47 ;	1,87	0,319
Precuneus right cortical thickness	-4,65	-9,73 ;	0,44	0,071	-3,45	-6,74 ;	-0,15	**0,041**	-2,90	-6,04 ;	0,23	*0,068*	-0,04	-3,38 ;	3,31	0,982	-1,11	-4,58 ;	2,37	0,514
Limbic lobe																				
Caudal anterior cingulate left cortical thickness	-1,41	-3,95 ;	1,14	0,263	-0,24	-2,18 ;	1,48	0,697	-0,28	-2,04 ;	1,48	0,743	0,08	-1,65 ;	1,81	0,926	0,97	-0,68 ;	2,62	0,232

	Purely motor			Adaptative pegboard			Adaptative balance			Balance			Quality		
	Coeff	**95% Conf. Interv.**	**p value**	**Coeff**	**95% Conf. Interv.**	**p value**	**Coeff**	**95% Conf. Interv.**	**p value**	**Coeff**	**95% Conf. Interv.**	**p value**	**Coeff**	**95% Conf. Interv.**	**p value**
Caudal anterior cingulate right cortical thickness	-2,15	-4,62 ; 0,32	0,084	-0,49	-2,41 ; 1,43	0,601	-0,41	-2,27 ; 1,45	0,653	1,19	-0,54 ; 2,92	0,168	0,15	-1,56 ; 1,87	0,854
Rostral anterior cingulate left cortical thickness	-1,78	-3,68 ; 0,12	*0,065*	-0,72	-2,12 ; 0,68	0,301	-0,37	-1,82 ; 1,08	0,603	0,61	-0,71 ; 1,93	0,348	0,78	-0,37 ; 1,92	0,171
Rostral anterior cingulate right cortical thickness	-2,29	-4,14 ; -0,45	0,017	-0,39	-1,48 ; 0,70	0,467	-0,10	-1,14 ; 0,93	0,837	-0,56	-1,55 ; 0,43	0,257	0,84	0,01 ; 1,67	9,047
Isthmus cingulate left cortical thickness	-1,75	-5,69 ; 2,19	0,367	-0,64	-3,39 ; 2,10	0,632	-0,54	-3,37 ; 2,30	0,699	1,53	-0,95 ; 4,01	0,215	-0,92	-3,23 ; 1,38	0,413
Isthmus cingulate right cortical thickness	-1,75	-4,33 ; 0,82	0,171	-0,80	-2,73 ; 1,12	0,397	-0,23	-2,21 ; 1,74	0,808	-0,13	-2,04 ; 1,77	0,885	0,23	-1,41 ; 1,87	0,772
Posterior cingulate left cortical thickness	-2,35	-5,97 ; 1,06	0,161	-1,77	-4,25 ; 0,71	0,153	-1,24	-3,65 ; 1,17	0,297	-0,02	-2,42 ; 2,37	0,984	-0,21	-2,37 ; 1,96	0,843
Posterior cingulate right cortical thickness	-0,89	-3,38 ; 1,61	0,469	-0,70	-2,46 ; 1,05	0,416	-0,59	-2,24 ; 1,06	0,469	-1,16	-2,73 ; 0,41	0,140	-0,91	-3,01 ; 1,20	0,379
Parahippocampal left cortical thickness	-0,84	-2,80 ; 1,12	0,384	-1,38	-2,94 ; 0,18	*0,081*	-0,83	-2,13 ; 0,47	*0,199*	-0,76	-2,05 ; 0,53	0,235	-0,26	-1,61 ; 1,09	0,692
Parahippocampal right cortical thickness	-2,29	-5,25 ; 0,68	0,124	-1,77	-3,89 ; 0,36	*0,099*	-1,90	-3,90 ; 0,09	*0,060*	-0,97	-3,02 ; 1,08	0,336	-0,93	-3,17 ; 1,32	0,400
Insula															
Insula left cortical thickness	-0,05	-0,53 ; 0,42	0,821	-0,26	-0,57 ; 0,05	0,100	0,03	-0,29 ; 0,35	0,849	0,25	-0,39 ; 0,53	0,087	0,14	-0,14 ; 0,41	0,305
Insula right cortical thickness	-0,05	-0,53 ; 0,42	0,811	-0,24	-0,55 ; 0,07	0,119	0,04	-0,28 ; 0,35	0,818	0,24	-0,04 ; 0,53	0,088	0,14	-0,14 ; 0,41	0,304

Table 2 : correlation between cortical thickness and ZNMA scores