*Curr Pediatr Res2021; 26 (1): 22-31* *ISSN 0971-9032*
*www.currentpediatrics.com*

# Multidimensional exploration of the neurodevelopment of children from 1 to 3 years old using the Neurodevelopment Scale 0-3 (NDS 0-3).

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## Abstract

**The first three years are of vital importance for children's neurodevelopment; however, this is not usually assessed at an individual level on a preventive basis. Our aim was to assess the dimensions of muscle tone, motor response, perception, rhythm-inhibition and adaptation-relationship in 209 children from 13 to 36 months of age and to identify those that did not show a level in accordance with their chronological age. Experts in child neuropsychology and educators applied the NDS 0-3 Scale, for neurodevelopmental disorders from 0 to 3 years of age. The results showed the assessment of five subjects with scores below the minimum levels corresponding to their age who needed a more in-depth diagnosis. Elements were identified in which the scores were below the minimum levels in all dimensions while, on average, the level of overall neurofunctional development was equal to or greater than the chronological age in the factors considered: muscle tone (5.56), motor response (5.36), perception (5.16), rhythm and inhibition (5.56) and adaptation and relationship (5.67). It was concluded that it is possible to identify the neurodevelopmental characteristics in muscle tone, motor response, perception, rhythm-inhibition and adaptation-relationship and to detect those who show a delay in their neurodevelopment in order to make a more profound diagnosis and implement the necessary interventions. The findings have important practical implications for the diagnosis, neurodevelopment and interventions related to children's needs and the prevention of disorders.**

**Keywords:** Neurodevelopment, Muscle tone, Motor response, Perception, Rhythm-inhibition, Adaptation-relationship.

*Accepted on 12th December 2021*

## Introduction

The first years of life are key to the physical, emotional and mental development of the human being, specifically the neuro-sensory-motor maturation.

Preclinical signs that later evolve into chronic diseases are increasingly recognised as neurodevelopmental phenomena [1,2] and relevant science is evolving faster than psycho-pedagogical and clinical applications [3].

For this reason, it is important to apply advanced child neurodevelopmental assessments, designed to understand and develop children's potential, pre-empt difficulties and also intervene and overcome them when these are detected.

In this study, work was focused on the assessment of motor response, perception, rhythm-inhibition and adaptation-relationship dimensions by applying the NDS 0-3 Scale.

### *Muscle tone*

Muscle tone is a complex neurological phenomenon, the basis of all motor skills and the maintenance of posture that participates in any movement and influences the whole personality [4].

Reflexes facilitate the tone in the tension and distension made by the muscles [5] and promote the maturation of the central nervous system, motor and cognitive development Geysztor, et al. In addition, tone and reflexes affect learning and behaviour in later life [6,7].

### *Motor response*

Different research shows that sensory and motor developments are fundamental bases for child development [8-11]. On the other hand, the home environment influences motor development and fine motor skills, and recent research with children aged 18-42 months such as Valadi and Gabbard [12] and other studies, also analyse case studies that highlight the importance of involving parents and teachers with children in their daily development and learning processes [13].

On the other hand, from the first years, motor disorders can be detected that should be identifiable through neuropsychological assessments.

### *Perception*

Sensory and perceptual development during the early years includes ensuring that visual abilities are in an acceptable refractive state [14,15].

In addition, the correct control of eye movements and visual skills acquired from the early years will be necessary to read and learn [16,17].

Another key sense for learning is listening because it influences a child's acquisition of language, vocabulary, and verbal expression [18]. Touch also favours sensory integration and all require observation and intervention [19].

### *Rhythm and inhibition*

The new-born starts from a very primitive point and, step by step, will have a rhythm and speed of neurofunctional development that requires synchronization and harmony in all dimensions which authors such as Ferré et al. [20] call "rhythm and inhibition".

Brain activity is carried out through a balance between excitation and inhibition of neurons and the neuronal networks need to be synchronised to carry out the correct processing of information and execution of behaviours; recent research shows that there is an association of changes in brain rhythms in the cortex that affect cognitive dysfunction disorders [21].

### *Adaptation and relationship*

At birth, the child organizes its internal world and adapts to the environment and evolves in the patterns of relationship with the environment, relationship and language [20].

Recent research shows that the reflective functioning of parents and their empathy have an impact on the care, security, regulation of emotions and development of children, although more training and social support is needed [22,23].

The action of parents and coordination with educators are key to their adaptation, relationship and language development [24].

There are currently different instruments that allow the assessment of developmental aspects: McClenaghan and Gallahue's Fundamental Pattern of Movement Assessment [25], Ulrich's The Gross Motor Development Test [26], and Movement Assessment Battery for Children (ABC-2) developed by Henderson et al. [27].

On this occasion and given that the interest is centered on the aforementioned dimensions, the NDS 0-3 Scales for assessing the level of neuro-senso-psychomotor development will be used [20].

Based on the above, the general objective of the study was to identify the characteristics of the neurodevelopment of 1-3-year olds.

The specific objectives were: 1) to establish the characteristics of neurodevelopment in the dimensions of muscle tone, motor response, perception, rhythm inhibition and adaptation in children aged 1-3, 2) to analyse the correlations that may exist between the different components and 3) to identify children who do not have the neurodevelopment level that corresponds to their age, in order to help achieve a more in-depth diagnosis and the appropriate interventions.

## Method

The design of the study was descriptive and correlational.

### *Sample*

The total sample consisted of 209 children (105 boys and 104 girls). The mean age was 26.8 months with a standard deviation of 6.10 months. Of the sample, 12% (13-18 months), 26% (19-24 months), 25% (25-30 months) and 37% (31-36 months).

The socio-economic level was medium (14.4%) and medium-high (85.6%). The inclusion criteria were to be enrolled in children's centres from 0 to 3 years of age with the written informed consent from the parents and the exclusion criteria to be free of serious neurodevelopmental deficits and/or disorders.

### *Instrument*

The NDS 0-3 of the neuro-senso-psychomotor assessment scale [20], aims at the prevention, development and treatment of disorders that affect the function of the child's Nervous System.

Five dimensions of neurodevelopment are assessed to be used as a guide and reference for the child's level of harmony. It is part of a multidisciplinary approach, based on previous scales such as those of Denver the Kent Scale (Table 1) [28-31].

| Muscle tone | Motor response | Perception | Rhythm and inhibition | Adaptation and relationship |
|---|---|---|---|---|
| Hands, mouth, tonic mouth control, legs, balance and body balance control. | Postural changes, on the ground, standing, in-hand manipulation, wandering, jumping, running, kicking. | Vision, hearing, touch, taste and smell. | Daily situations, in the face of rhythmic and attractive stimuli, sleep patterns, eating habits and sphincter control. | Language, exploration of the environment, response in new places, to forbidden objects, to what causes fear. |

***Table 1.*** Neurodevelopmental dimensions of NDS 0-3.

The format corresponds to children from 0 to 36 months for each one of the dimensions. In this study, the corresponding sections from 13 to 36 months were used, containing 72 elements in each at 3-month intervals during the first year and each six months in the second and third year.

Each of the sections brings together the most characteristic behaviours of the age interval being assessed. It is necessary to

observe the child's behaviour and responses in order to assign a value and, subsequently, to indicate in the table the value obtained for each item.

Finally, the Harmony Range rating is given, which corresponds to the behaviour manifested in ordinary life, using a Likert scale (it can have a variation of +/- two months and the range of responses is the result of the subject being above, equal or below his or her age. The scoring assigned: +2 months above their age=7 points; +1 month above their age=6 points; Equal to their age=5 points: -1 month below their age=4 points; -2 months below their age=3 points; -3 months below their age=2 points; Alarm=1 point.

Scores below 5 points are below chronological age and are interpreted as disharmony. In order for the child's development to be harmonious, what is really important is that all the parameters are level, even if a chronological delay of one or two months is noted; it is considered that some children need more time to develop all the systems and the important thing is to know this and to favour the process, without forcing it.

It is considered an alarm if scores are 3 months or more below their age and in those cases, it is advisable to consult a child development specialist to carry out an in-depth diagnosis.

The NDS 0-3 scale has a reliability of 0.968. All the scales show reliability over .80 and the different subscales of the assessed dimensions have good reliability (**α** from Cronbach: . 905 Muscle tone; .890 Motor response; .901 Perception; .832 Rhythm; .945 Adaptation and relationship).

### *Procedure*

First of all, we proposed carrying out a Neurodevelopmental Project with children from 0-3 years of age to a director of children's centre through the participation of all the children's educators, which was very well accepted. However, literature shows that educators sometimes lack knowledge of how neurodevelopment can affect academic and social performance [32] and, consequently, we provided four scientific-practical training sessions to understand the needs of each child and to be able to manage them in the school environment as indicated by recent research [33], so that they would have the specific preparation and tools necessary to carry out the Project. The educators had the corresponding official academic qualifications and taught the activities of the Education Project to the children in the classroom throughout the day. The classrooms were organized in different groups, according to the children's chronological age. The parents of each participant then signed an informed consent form.

In the following phase, three psychologists and the educators of the children's centres applied the NDS 0-3 Scale; each educator observed the behaviour of each child in his or her group and assessed and completed the assessment of each item in the five dimensions in the register, always with the advice of the psychologists throughout the process.

This study was approved by the Ethics Committee of the International University of La Rioja, Section of Developmental surveillance and screening of infants and young children.

### *Data analysis*

The data were coded and analysed using the SPSS 22.0 statistical package. Descriptive analyses (mean, median, standard deviation, and maximum and minimum values) and correlation analyses were performed between the neurodevelopmental dimensions of the age groups (13-18, 19-24, 25-30 and 31-36 months). Spearman's correlation coefficients were obtained between the different variables in each age range.

## Results

### *Descriptive analysis*

The subjects presented an overall level of development slightly higher than their age (5.56), in all dimensions, although lower average levels and age-specific lows were identified, as we will analyse in the following sections (Table 2).

| | Muscle tone | Motor response | Perception | Rhythm-inhibition | Adaptation -relationship |
|---|---|---|---|---|---|
| Mean | 5.56 | 5.29 | 5.16 | 5.56 | 5.67 |
| Median | 5.36 | 5.34 | 5.33 | 5.46 | 5.40 |
| Standard deviation | 0.88 | 1.29 | 1.58 | 0.88 | 0.95 |
| Minimum | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Maximum | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |

***Table 2.*** Descriptive statistics for all dimensions.

### *Muscle Tone (MT)*

All the subjects showed a development of muscle tone above their age (Table 3). The highest score was 25 to 30 months and the muscle tone of the legs, back and balance control were almost one month higher than their age. Between 13-18 months, 19-24 months and 31-36 months showed lower average levels, except for 31-36 months in tonic mouth control, which was one month above their age.

| Age months | Body balance | Hands | Mouth | Legs | Back | Balance control | Tonic mouth control |
|---|---|---|---|---|---|---|---|
| 13-18 | 5.192 | 5.318 | 5.264 | 5.346 | 5.509 | N/A | N/A |
| 19-24 | 5.406 | N/A | 5.465 | 5.689 | N/A | 5.548 | N/A |
| 25-30 | 5.643 | N/A | 5.849 | 5.868 | N/A | 5.845 | N/A |
| 31-36 | 5.000 | N/A | 5.582 | N/A | N/A | N/A | 5.859 |

***Table 3.*** Muscle tone indicator averages ("N/A" {Not applicable] indicates not included in this age group).

### *Motor Responses (MR)*

The indicator averages showed a level equal to or higher than age, indicating a good level of harmony in motor response (Table 4).

| Age months | Postural changes | On the ground | Standing | Balance control | In-hand manipulation | Wandering | Jumping | Running | Kicking |
|---|---|---|---|---|---|---|---|---|---|
| 13-18 | 5.168 | 5.321 | 5.310 | 5.384 | 5.328 | N/A | N/A | N/A | N/A |
| 19-24 | N/A | N/A | N/A | N/A | 5.836 | 5.709 | 4.979 | 5.364 | 5.436 |
| 25-30 | N/A | N/A | N/A | N/A | 5.963 | 5.656 | 5.753 | 5.704 | 5.840 |
| 31-36 | N/A | N/A | N/A | N/A | 5.467 | 5.701 | 5.582 | 5.526 | 5.422 |

***Table 4.*** Motor response indicator averages.

### *Perception (P)*

The indicator averages, showed that the 31-36 months subjects were below their age in touch and the 25-30 months subjects had greater vision and hearing development (Table 5).

| Age months | Vision | Hearing | Touch | Taste | Smell |
|---|---|---|---|---|---|
| 13-18 | 5.356 | 5.58 | 5.448 | 5.63 | 5.614 |
| 19-24 | 5.414 | 5.668 | 5.693 | N/A | N/A |
| 25-30 | 5.795 | 5.839 | 5.573 | N/A | N/A |
| 31-36 | 5.602 | 5.59 | 4.918 | N/A | N/A |

***Table 5.*** Perception indicator averages.

### *Rhythm and Inhibition (R-I)*

The indicator averages showed that the subjects presented a level of development in accord with their age and higher (Table 6).

| Age months | In repeated day to day situations | To rhythmic or attractive stimuli | Sleeping patterns | Eating habits | Sphincter control |
|---|---|---|---|---|---|
| 13-18 | 5.576 | 5.552 | 5.379 | 5.443 | N/A |
| 19-24 | 5.625 | N/A | 5.303 | 5.778 | N/A |
| 25-30 | 5.705 | N/A | 5.611 | 5.753 | 5.64 |
| 31-36 | 5.585 | N/A | 5.18 | 5.665 | 5.74 |

***Table 6.*** Average of rhythm and inhibition indicators.

### *Adaptation and relationship (A-I)*

The indicator averages, showed that the subjects were above their age (Table 7).

| Age months | Language | To unfamiliar objects | Exploring the environment | To an unfamiliar environment | To forbidden objects | When something causes fear |
|---|---|---|---|---|---|---|
| 13-18 | 5.2 | 5.48 | 5.616 | 5.636 | 5.231 | N/A |
| 19-24 | 5.422 | 5.84 | 5.792 | N/A | 6 | 5.726 |
| 25-30 | 5.877 | 5.923 | 5.882 | N/A | 6 | 5.751 |
| 31-36 | 5.489 | 5.57 | 5.684 | N/A | 5.694 | 5.614 |

***Table 7.*** Adaptation and relationship indicator averages.

### *Minimum values*

The minimum values of the results in all dimensions were analysed.Muscle tone: There were subjects below their age at all ages.

From 13-18 months, body balance one month younger than their age; 19-24 months, body balance and muscle tone of the legs. 25-30 and 31-36 months, lower body balance more than two months below their age (Table 8).

| Age months | Body balance | Hands | Mouth | Legs | Back | Balance control | Tonic mouth control |
|---|---|---|---|---|---|---|---|
| 13-18 | 4 | 4.7 | 4.75 | 4.6 | 4.75 | N/A | N/A |
| 19-24 | 4.3 | N/A | 3.7 | 4.6 | N/A | 4.6 | N/A |
| 25-30 | 2.6 | N/A | 4.3 | 3.6 | N/A | 4 | N/A |
| 31-36 | 3.5 | N/A | 4.3 | N/A | N/A | N/A | 4.6 |

***Table 8.*** Minimum values for muscle tone indicators.

**Motor responses:** Some subjects showed scores one month below their age and 31-36 months two months below their age in kicking (Table 9).

| Age months | Postural changes | On the ground | Standing | Balance control | In-hand manipulation | Wandering | Jumping | Running | Kicking |
|---|---|---|---|---|---|---|---|---|---|
| 13-18 | 3.6 | 4.5 | 4.25 | 4 | 4.25 | N/A | N/A | N/A | N/A |
| 19-24 | N/A | N/A | N/A | N/A | 4.3 | 3.7 | 4.2 | 4.25 | 4.3 |
| 25-30 | N/A | N/A | N/A | N/A | 4.25 | 4 | 4.52 | 4.25 | 4 |
| 31-36 | N/A | N/A | N/A | N/A | 4 | 4.33 | 4.25 | 4 | 3 |

***Table 9.*** Minimum values for motor response indicators.

**Perception:** The minimum values were close to chronological age; the maximum discrepancy was 31-36 months in touch with two months below age (Table 10).

| Age months | Vision | Hearing | Touch | Taste | |
|---|---|---|---|---|---|
| 13-18 | 4.6 | 5 | 5 | 5 | 5 |
| 19-24 | 4.06 | 4.75 | 4.5 | N/A | N/A |
| 25-30 | 4 | 3.7 | 3.75 | N/A | N/A |
| 31-36 | 4.33 | 4 | 2.5 | N/A | N/A |

***Table 10.*** Minimum scores for perception indicators by age.

**Rhythm and inhibition:** There were subjects below their age in all sections (Table 11). Of particular note was a 25-30 month old subject who showed a three month lower level than his age in sleep, eating habits and in adaptation to daily situations.

| Months | In repeated day to day situations | To rhythmic and attractive stimuli | Rhythmic sleep inhibition | Eating patterns | Sphincter control |
|---|---|---|---|---|---|
| 13-18 | 4.3 | 5 | 4.6 | 5 | N/A |
| 19-24 | 4 | N/A | 4 | 4 | N/A |
| 25-30 | 4.3 | N/A | 2 | 3.3 | 4.66 |
| 31-36 | 3.6 | N/A | 4 | 4.3 | 4 |

***Table 11.*** Minimum scores for rhythm and inhibition indicators.

**Adaptation and relationship:** They were below the age of 25-30 months in reactions to the forbidden and at 31-36 months, two months below their age in reactions when something frightened them (Table 12).

| Months | Language | To unfamiliar objects | Exploring the environment | To unfamiliar environments | To the forbidden | When something causes fear |
|---|---|---|---|---|---|---|
| 13-18 | 4.6 | 5 | 5 | 5 | 5 | N/A |
| 19-24 | 4 | 4.6 | 4.6 | N/A | 4.5 | 5 |
| 25-30 | 4 | 4.33 | 4.66 | N/A | 3.7 | 5 |
| 31-36 | 4.3 | 4.33 | 4.33 | N/A | 4 | 3 |

***Table 12.*** Minimum scores for adaptation and relationship indicators.

## *Correlation analysis*

Spearman's correlation analysis was carried out between the different variables in each age range, revealing that statistically significant correlations were obtained between most of the variables in the different age groups.

The outstanding results of the correlations obtained between the different dimensions of Muscle Tone, Motor Response, Perception, Rhythm and Inhibition and Adaptation and Relationship are presented.

**Muscle tone:** Muscle tone in (13-18 months) personal equilibrium correlated ($<r$ 0.7<0.8, $p<0.05$) with MR in kicking and in-hand manipulation, with P in vision, with R-I in eating habits and with A-R in exploring unfamiliar objects and environments and dealing with fear.

In (19-24 months) the MT correlated with MR also in running and with R-I and in A-R also when frightened. In addition, in (25-30 months) it correlated body balance with the MR ($0.7<r<0.8$, $p<0.05$) to walking and jumping, wandering and kicking and in (35-36 months) it correlated with in-hand manipulation.

The MT (31-36 months) obtained high relationships ($0.7<r<0.8$; $p<0.05$) with P in vision and A-R in reactions to unfamiliar objects, environments and situations causing fear. The interactions have shown showed the relationship between muscle tone and neurodevelopmental dimensions and, consequently, the importance of assessing and developing this factor.

**The motor response:** The motor response correlated at 13-18 months with very strong relationships ($r>0.8$, $p<0.05$) in motricity on the ground, in-hand manipulation and balance control with A-R in exploration of the environment and environmental stimuli, and reaction in the face of the forbidden. In 19-24 months there were correlations ($r>0.8$, $p<0.05$) of muscle tone in the back and legs with MR in in-hand manipulation, kicking, with P in vision, R-I in eating habits and A-R in adapting to different situations. In 25-30 months it also correlated with P in vision ($r>0.8$, $p<0.05$) and at 31-36 months statistically significant relationships were reached with P in all the indicators, with R-I and A-R in reaction to an unfamiliar object, exploration of the environment and reaction when frightened. These results indicate the interaction between motor processes and visual and auditory perceptive processes that favour rhythm-inhibition and different dimensions such as perception that favour exploration of and adaptation to the environment.

**Perception:** Perception in 13-18 months correlated with R-I, ($r>0.8$, $p<0.05$) in repetitive day to day situations and in 19-24 months with sleeping habits as well. In 25-30 months they also correlated all vision and hearing indicators with R-I ($r>0.8$, $p<0.05$) and with all A-R indicators. At 31-36 months it correlated ($r>0.8$, $p<0.05$) MR with in-hand manipulation, with R-I and A-R to unfamiliar objects, experiences and fear. These interactions indicate the importance of perception in the processing of information in the brain and its relationship with the processes of neurodevelopmental rhythm and inhibitory control at these ages.

**Rhythm and inhibition:** Rhythm and inhibition in 13-18 months showed a strong correlations with A-R ($r<0.8$, $p<0.05$) in environmental exploration and response to unfamiliar situations; in 19-24 months with P and A-R in eating habits; in 25-30 months with P, in vision and hearing indicators ($r> 0.8$, $p<0.05$) and in A-R with almost all indicators. In 31-35 months it correlated with wandering, jumping, and in-hand manipulation MR ($r<0.7$ $p<0.05$) and with A-R indicators ($r<0.8$; $p<0.05$) in everyday situations, reaction when encountering an unfamiliar object, exploring the environment, and reaction when frightened of something. The meaning of

the relationships obtained could be in line with the findings on brain activity, which is governed by the balance between neuronal excitation and inhibition, and in the synchronisation necessary for correct information processing [21]; these processes are present in the neurodevelopmental dimensions analysed in this study and the results reflect their relationship.

**Adaptation-relationship:** Adaptation-relationship in 13-18 months correlated ($r>0.8$, $p<0.05$) with the MT of the back when exploring unfamiliar objects, new environments and when frightened and in 19-24 months also when frightened. At 25-30 months it correlated ($r>0.8$, $p<0.05$) with MT in adapting to unfamiliar situations, with P in vision and hearing, with R-I in almost all indicators. In 31-36 months, it correlated with MT ($r<0.8$; $p<0.05$) in everyday activities, reaction to encountering an unfamiliar object, exploring the environment, and reaction when frightened, with MR, P, and R-I. This dimension shows relationships with the other dimensions revealing that adaptation and relationships with others, including relationship and language, are a reflection of the child's neurodevelopment.

### *Analysis of the groups and identification of subjects requiring a more in-depth diagnosis*

For the second objective, the results of each subject were analysed individually and those who had scores below their age in all five dimensions were selected: subjects Nr. 3, Nr. 10 and Nr. 11 were from 25 to 30 months and subjects Nr. 5 and Nr. 7 from 31-36 months. Parents were subsequently informed in a personal interview and a more in-depth diagnosis with a professional specialized in child neurodevelopment was suggested. In addition, the educators of these children were guided so that they could receive specific personal attention, according to the results obtained in each individual case.

In the evaluation of group results, indicators below their age were detected in some dimensions in two of the 31-36 months groups. In group 2c the lowest scores were in muscle tone, body balance and visual and auditory perception. In group 2d the lowest scores were in muscle tone (body balance and tonic leg control, perception, vision, hearing and touch) and in rhythm-inhibition (eating habits and sphincter control). In addition, it is noteworthy that 12 out of 14 children had lower scores in motor response (jumping, running and in-hand manipulation) and in adaptation-relationship (language, reaction to the unknown and integration and respect for rules). A specific plan of activity was proposed to improve the indicators in each of these 2c and 2d groups according to the results obtained and the educators were trained to carry this out with the necessary preparation.

## Discussion

To meet the objectives set out in this study, a questionnaire corresponding to the NDS 0-3 scale was applied. This assessment instrument has proved effective in identifying the dimensions of neurodevelopment of all children and age-related differences. The NDS 0-3 provides for the measurement of different dimensions within a single instrument, which is not usually a feature of other instruments previously used for this age group, such as the Neurosensory Motor Development Assessment [34], the Sensory Profile for Young Children [35], or the Fundamental Movement Pattern Assessment instrument [25].

### *Neurodevelopmental dimensions and correlations*

With regard to objectives one and two, to analyse the results of the neurodevelopmental dimensions and analyse the correlations between these dimensions, the results indicate that the children in the study aged between 1 and 3 show a level of neurodevelopment that is slightly higher than their age: muscle tone, motor responses, rhythm-inhibition and adaptation-relationship. This overall result could be due to the good practice of the professionals working in the children's centres, as they apply neurodevelopmental programmes with innovative methodologies, together with the continuous monitoring of the director and the guidance team. Our results are in line with research by Gwernan-Jones et al. [33] which highlights the importance of teacher training to understand the needs of each child and to be able to manage them in the school environment and the training they receive [32]. In addition, there is good coordination with parents who have access to information about the activities of the schools and about the development of each of their children in line with other studies on parental performance [22-24]. The medium to high socio-cultural level of the participants could also be an important factor.

Analysing each dimension, in terms of muscle tone, the results show that subjects generally have a good level, particularly those between 25 and 30 months, who have the highest level of muscle tone in mouth, legs and balance. This assessment is important, as muscle tone is a dimension that can serve as a prognostic measure, and our findings are related to recent studies such as those by Cunha et al. [36] that relate tone to motor skills and cerebellum activity when assessing the movements of premature infants. In addition, tone drives nervous system maturation, motor and cognitive development, along with behaviours at later stages, as shown by several studies [5-7]. In our study muscle tone was correlated with other dimensions of motor response, perception, rhythm-inhibition and adaptation and relationship, showing their interaction with all of them.

Motor response is one of the most important aspects at this age and in our study, this was consistent with the chronological age in subjects aged 13-18 months and older in in-hand manipulation, walking, jumping and running 25-30 months and in wandering 25-30 months. Genetics and the opportunities provided by the environment in exercising basic movements and motor experience, make it possible for the cerebellum, subcortical nuclei and motor areas to carry out neuromotor processes [9]. These results are in line with our findings and other studies that reflect the importance of providing opportunities for motor development in children's centres and at home, as in the research carried out with 18-42-month-old children by Valadi and Gabbard [12]. In addition, motor responses were correlated with dimensions of muscle tone and perception; vision in particular, will serve as a basis for visual

coordination in reading and writing. It also correlated with rhythm-inhibition and adaptation-relationship, which will favour more complex motor skills, needed for later games and sports activities, as stated in previous studies [37-39].

The results relating to perception showed levels in line with age and above in 25 and 30 months, almost one month higher, especially in vision and hearing, which will favour later learning, according to research on visual skills acquired from the early years, necessary for learning [15-17]. Perception correlated with dimensions of muscle tone, motor response, rhythm-inhibition, and adaptation-relationship; these findings are in line with other recent research showing the key role of the senses such as hearing, because it influences a child's acquisition of language, vocabulary, and verbal expression [18]. Consequently, it is useful to know if there are hearing difficulties in order to ensure the neurodevelopmental conditions required for spoken language, reading, and arithmetic [40,41].

In rhythm and inhibition, the subjects generally showed values of a developmental level according to their age. It is noteworthy that a 25 to 30 month old subject had a sleep rhythm three months below their age, although from the first month of life it is essential to organize the basic rhythms of eating, waking and sleeping, as reflected in other studies such as those by Ferré et al; Rosselli et al. [20,42] pointing out their incidence in the integration and organization of information, together with the inhibition of automatic responses that continue to improve throughout childhood. According to other research by Gwernan-Jones et al. [33], which showed the relationship between the development of inhibition capacity and attention, this study is in line with the prevention of attention difficulties to avoid disorders such as ADHD and favour neurodevelopment.

In addition, rhythm-inhibition correlated with the other dimensions and in adaptation-relationship, with daily activities, exploration of the environment, affecting the experiences and image of oneself.

Adaptation-relationship showed an equal or higher level of development, highlighting 25 to 30 months of age, specifically in language, exploration of objects and reactions to forbidden or frightening situations. Furthermore, it correlates with muscle tone, and motor response, with perception and rhythm-inhibition; these findings are in agreement with other studies that showed the relationship between adaptation to the environment, with motor skills, language and cognition and positively influence language development [24,43].

This study also served to identify threshold values in cases of children who show difficulties in some or all areas of development. Therefore, the group results were analysed and it was found that two groups of 31-36 months showed indicators of some dimensions below their age and specific activity plans were proposed to improve each dimension that could be enhanced.

This is a key issue in this type of study, according to researchers who have demonstrated the importance of identifying disorders, as in the case of motor development [44], as well as detecting them in time to implement the necessary interventions [45]. The results were shown to each of the educators and a plan of activities was proposed to improve the lower level indicators.

### *Identification of children in need of further diagnosis*

For objective three, to identify the subjects that need a more in-depth diagnosis, all the indicators and dimensions of each of the 208 subjects in the sample were analysed; the results showed that there were five children with scores below their age in different indicators of the dimensions evaluated (3 children of 25-30 months and 2 children of 31-36 months). This is one of the most important findings in this study because, thanks to the application of the NDS 0-3 instrument, it has been possible to detect that these five children had a level of neurodevelopment 2 and 3 months below their chronological age; consequently, it was possible to inform parents and educators and suggest a more in-depth diagnosis be made by a doctor or psychologist specialised in child neurodevelopment. In this way, it was possible to carry out the necessary interventions for these children with the necessary effectiveness, as proposed by recent research [1,2] and others that state that the relevant advances in science could be applied more quickly in the clinical [3], psycho-pedagogical and educational fields, collaborating together in the care of each individual case. In this way, prevention, development and attention to specific needs could be favoured, avoiding disruptive behaviours and disorders which are usually expressed before the age of 5 and can be serious, if intervention is not early.

The limitations of the study are related to the selection of the sample, since there were no children between 0 and 12 months in the children's centres in the sample of participants [46].

## Conclusion

It can be concluded that it is possible and advisable to identify the characteristics of the neurodevelopment of children between 1 and 3 years of age, in the dimensions of muscle tone, motor responses, perception, rhythm-inhibition and adaptation-relationship. It is also possible to identify children who show a delay in their neurodevelopment in order to make a more in-depth diagnosis and implement the necessary interventions. Our most important contribution is to show a line of research to assess key dimensions of neurodevelopment in children from 1 to 3 years old in a single instrument (ND 0-3), which complements other existing instruments. The differential is practical and formative, because it can be applied by the child educator, who knows the children best because he or she is with them daily in the classroom, together with a psychologist who is responsible for the preparation and supervision of the educators and provides the required materials and advice. Our findings serve to expand the scientific literature in this field and have practical implications for the neurodevelopment of all children at an early age, to detect any delays with respect to chronological age and to

identify subjects that require a more in-depth diagnosis. Furthermore, this study opens new lines for future research such as designing programmes related to each dimension for 0-3 years, longitudinal studies, the application to premature children and the development of further similar assessment instruments for children from 3 to 6 years of age. The application of the NDS 0-3, already started in other countries, can lead to comparative studies and the creation of innovation and collaborative research networks that provide a greater scientific basis and professionalism in the care of the first years of life.

## Acknowledgement

We thank Dr. Jorge Ferré and Dr. Mar Ferré, for their contribution to child neurodevelopment and the support received from the Medical Institute for Child Development.

We also thank the Director and teachers of the "La Buhardilla" Children's Centres for their collaboration and help in this research.

## Funding

This study has been funded by the Vice-Rectorate for Research of the International University of La Rioja (NYE-EDUC Research, Project 06 on the Application of Neuropsychology to Education, Neuropsychological Assessment Instruments Section).

## Conflicts of Interest

The authors declare they have no financial interests.

## Ethics Approval

Approved by the Ethics Committee of the International University of La Rioja in Section of Developmental surveillance and screening of infants and young children.

## Consent to Participate

Informed written consent of parents.

## Consent for Publication

The authors consent to publication.

## Availability of Data and Material

The data will be available to those who request it.

## References

1. Franklin JC, Jamieson JP, Glenn CR, et al. How developmental psychopathology theory and research can inform the Research Domain Criteria (RDoC) project. J Clin Child Adolesc Psychol 2015; 44: 280-290.
2. Casey BJ, Oliveri ME, Insel T. A neurodevelopmental perspective on the Research Domain Criteria (RDoC) framework. Biol Psychiatry 2014; 76: 350-353.
3. Mittal VA, Wakschlag LS. Research Domain Criteria (RDoC) grows up: Strengthening neurodevelopmental investigation within the RDoC framework. J Affect Disord 2017; 216: 30-35.
4. Bueno MªL, Del Valle S, De la Vega M. Perceptual-motor content, motor skills and coordination throughout the entire life cycle. Spain: Virtual Sports 2011.
5. Gieysztor E, Choińska A, Paprocka-Borowicz M. Persistence of primitive reflexes and associated motor problems in healthy preschool children. Arch Med Sci 2018; 14(1): 167-173.
6. Hamer EG, Hadders-Algra M. Prognostic significance of neurological signs in high-risk infants-A systematic review. Dev Med Child Neurol 2016; 58: 53-60.
7. Chinello A, Di Gangi V, Valenza E. Persistent primary reflexes affect motor acts: Potential implications for autism spectrum disorder. Res Dev Disabil 2018; 83: 287-295.
8. Da Fonseca, V. Psychomotor observation manual. Barcelona: Inde 2008.
9. Ferré J, Aribau E. The neuro-functional development of the child and its disorders. Vision, learning and other cognitive functions. Barcelona: Lebón 2008.
10. Hormiga CM, Camargo DM, Orozco LC. Reproducibility and convergent validity of the abbreviated development scale and a Spanish translation of the neurosensory motor development assessment instrument. Biomedical 2008; 28: 327-346.
11. Zelaznik HN. The past and future of motor learning and control: What is the proper level of description and analysis? Kinesiol Rev 2014; 3: 38-43.
12. Valadi S, Gabbard C. The effect of affordances in the home environment on children's fine and gross motor skills, Early Child Dev Care 2020; 190(8): 1225-1232.
13. Sousa J, Loizou E, Fochi P. Participatory pedagogies: Instituting children's rights in day to day pedagogic development. Eur Early Child Educ Res J 2019; 27(3): 299-304.
14. Hopkins S, Narayanaswamy S, Vincent S, et al. Do reduced visual acuity and refractive error affect classroom performance? Clin Exp Optom 2019; 103: 278-289.
15. Medrano S. Influence of the visual system in learning the reading process. Transl Vis Sci Technol 2011; 9: 91-103.
16. Reis M, De Araujo D, Loew S, et al. Spectral overlays for reading difficulties: Oculomotor function and reading efficiency among children and adolescents with visual stress. Sage 2020; 127: 490-509.
17. Commodari E, Guarnera M, Di Stedano A, et al. Children learn to read: How visual analysis and mental imagery contribute to reading performance at different stages or reading acquisition. J Psycholinguist Res 2020; 49: 59-72.
18. Keffala B, Scarpino S, Scheffner C, et al. Vocabulary and phonological abilities affect dual language learner's consonant production accuracy within and across languages. Am J Speech Lang Pathol 2020; 29: 1193-1211.
19. Ayres AJ. Sensory integration in children. Hidden sensory challenges. Madrid: TEA 2008.

20. Ferré J, Ferré M. The neuro-senso-psychomotor development of the first three years of life. Spain: Jorge Ferré Veciana 2005.
21. Ruiz- Mejias M, Martinez de Lagran M, Mattia M, et al. Overexpression of Dyrk1A, a down syndrome candidate, decreases excitability and impairs gamma oscillations in the prefrontal cortex. J Neurosci 2016; 36: 3648- 3659.
22. Borelli JL, Stern JA, Marvin MJ, et al. Reflective functioning and empathy among mothers of school-aged children: Charting the space between. Emotion Advance online publication 2020.
23. Landry SH. The role of parents in early childhood learning. Encyclopaedia on Early Childhood Development 2014.
24. Houwen S, Visser L, van der Putten A, et al. The interrelationships between motor, cognitive and language development in children with and without intellectual and developmental disabilities. Res Dev Disabil 2016; 53: 19-31.
25. McClenaghan BA, Gallahue DL. Basic movements. Its development and rehabilitation. Buenos Aires: Panamericana 1978.
26. Ulrich DA. Gross motor development test (2nd edn). Austin: Pro-ed 1985.
27. Henderson SE, Sugden D, Barnett L. Movement evaluation battery for the second edition of children. London: Pearson 2007.
28. Frankenburg WK, Dodds JB. The Denver developmental screening test. J Pediatr 1967; 71(2): 181-191.
29. McCarthy D. MSCA: McCarthy scale of skills and motor skills for children (3rd edn). Madrid: TEA, SA 1996.
30. McCarthy D. McCarthy scale of skills and motor skills for children. Madrid: TEA, SA 1998.
31. Bayley N. Bayley scales of infant development (2nd edn). San Antonio, TX: The Psychological Corporation 1993.
32. Ljusberg AL. The structured classroom. Int J Incl Educ 2011; 15(2): 195-210.
33. Gwernan Jones R, Moore DA, Cooper P, et al. A systematic review and synthesis of qualitative research: The influence of school context on symptoms of attention deficit hyperactivity disorder. Emot Behav Diffic 2016; 21(1): 83-100.
34. Burns YR, Ensbey RM, Norrie MA. The Neurosensory Motor Development Assessment. Part 1: Development and administration of the test. Aust J Physiother 1989; 35:141-9.
35. Dunn W, Daniels DB. Initial development of the infant/ toddler sensory profile. J Early Interv 2002; 25(1): 27-41.
36. Cunha M, Correa F, Cadete A, et al. Prognostic value of cerebellar growth and general movement assessments for the neurodevelopment of the large premature infant between 18 and 24 months of corrected age. Rev Neurol 2017; 64: 63-9.
37. Gallahue D, Ozmun J. Understand motor development: infants, children, adolescents. New York: McGraw Hill 2006.
38. Stodden D, Goodway J. The dynamic association between the development of motor skills and physical activity. J Phys Educ Recreat Dance 2007; 78(8): 33-49.
39. Stodden D, Goodway J, Langendorter S, et al. A developmental perspective on the role of motor skill competence in physical activity: an emerging relationship. QUEST 2008; 60(2).
40. Tomblin J, Oleson J, Ambrose S, et al. Aided hearing moderates the academic outcomes of children with mild to severe hearing loss. Ear Hear 2020; 41: 775-789.
41. Hallahan D, Pullen P, Kauffman J, et al. Exceptional learners. Oxford Research Encyclopaedia of Education 2020.
42. Roselli M, Jurado Ma B, Matute E. The executive functions through life. J Neuropsychiatry Clin Neurosci 2008; 8(1): 23-46.
43. Washington-Nortey, PM, Zhang F, Xu Y, et al. The impact of peer interactions on language development among preschool English language learners: A systematic review. Early Childhood Educ J 2020.
44. Kroes M. Early motor, psychosocial, and behavioural characteristics of attention deficit hyperactivity disorder. Maastricht: University of Maastricht 2000.
45. American Academy of Pediatrics. Developmental surveillance and screening of infants and young children. Committee for Children with Disabilities. Pediatry 2001; 108: 192-5.
46. García-Tornel F, Reuter J. Sequence of child development up to 15 months of age, based on parental information, Kent Child Development Scale. Rev Esp Pediatr 1996; 52(3): 234-244.

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