Alma Mater Studiorum – Università di Bologna

DOTTORATO DI RICERCA IN

Scienze Psicologiche

Ciclo XXIX

Settore Concorsuale di afferenza: 11/E1 Psicologia generale, Psicobiologia e psicometria

Settore Scientifico disciplinare: MPSI/03 Psicometria

DEVELOPMENTAL TRAJECTORIES AND NORMATIVE PROFILES OF MOTION AND FORM PERCEPTION

Presentata da: **Luca Mandolesi**

Coordinatore Dottorato

Prof.ssa Monica Rubini

Relatore

Prof.ssa Mariagrazia Benassi

Esame finale anno 2017

DEVELOPMENTAL TRAJECTORIES AND NORMATIVE PROFILES OF MOTION AND FORM PERCEPTION

Abstract:

The research focuses on the study of the methods useful to evaluate the developmental trajectories for global motion perception and global form perception. The studies aim to present two different instruments created in order to evaluate the dorsal and ventral streams functionalities and to analyze their psychometric characteristics.

The first study presents the Motion and Form perception tests as new tools to investigate motion and form perception accuracy. The use of these tests allows to cope with some of the criticism reported in other studies presented in literature. The tests have been evaluated in a large sample of children of different ages.

The second study evaluates the applicability of a specific psychophysical function which allows to analyze the accuracy profiles obtained by Motion and Form coherence test. The response profile of the two tasks are fitted with a half-normal distribution function, that estimates the discrimination performance (i.e. the number of correct responses) on the basis of the coherence level of a stimulus. Moreover, the use of the function allows to statistically define the perceptive thresholds of the two test and to compare them.

The third study presented analyzes the developmental trajectories of motion detection and form discrimination abilities in a sample of typically developing children (4 to 13 years) and adults. Moreover, this study allows to define the normative scores for motion coherence and form coherence tests calculated with different normative indexes in the different age groups.

The fourth study investigates if motion and form tests can recognize specific deficits in clinical populations. The differences between motion and form perception accuracy are evaluated in children with different genetic syndromes (Noonan syndrome and 22q11.2 deletion syndrome) and in controls. The different populations show specific results in motion and form perception abilities

SUMMARY

1. Introduction

The ability in motion perception is considered a sensitive and reliable measure of typical and atypical brain development. Because of the motion perception is considered a golden standard to measure Dorsal stream functioning, some authors referred to this issue as “Dorsal stream vulnerability hypothesis”. Indeed, deficits in motion perception are found to be related to definite neurodevelopmental disorders (Grinter, Maybery, & Badcock, 2010), such as genetic syndromes (Alfieri et al., 2001), preterm born children (Atkinson & Braddick, 2007; Birtles et al., 2007), autism spectrum disorders (Milner et al., 2002; Grinter et al., 2010), developmental dyslexia (Talcott, 2000), and schizophrenia (Martinez et al., 2008). For some of these disorders, the specificity of the motion perception deficit is used as biomarker of the disorder (Braddick, Atkinson, & Wattam-Bell, 2003). Nevertheless, some findings failed to confirm this hypothesis (Grinter, Maybery & Badcock, 2010) demonstrating that the visual deficit overlapped with other cognitive deficits.

1.1 Vision system and methods of measurement of Dorsal and Ventral pathway

Vision has been investigated in former literature both from a cognitive and a neuropsychological perspective and quite recently these approaches have been integrated. Behavioral findings have been considered together with neuroimaging evidences, providing a better explanation of the different aspects of vision perception. However, a relevant part of the literature has dealt with difficulty in the integration of the different results on the same topic (Burr & Thompson, 2011; Nishida, 2011).

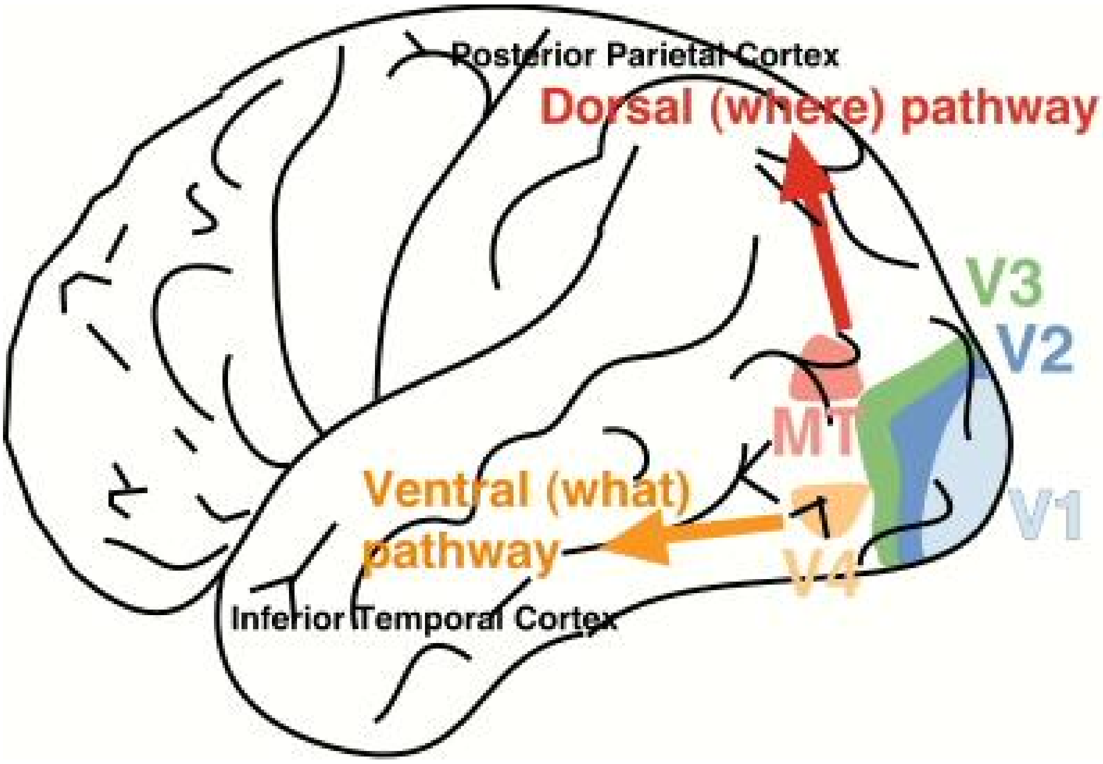

Fig. 1 – Dorsal and Ventral pathways

It has been argued that the visual information is hierarchically processed in the cortex: V1 cortex elaborates information about orientation, curvature, spatial or temporal frequency, color perception from a small part of the visual field. The regions in the extrastriate cortex combine this information to construct global representation of the stimuli (Maunsell & Newsome, 1987). Although it was initially supposed that the elaboration of visual information proceeded in feed-forward direction, in a direct linear way, later studies discovered numerous feed-back and feed-forward interactions between the two streams (Zeki & Shipp, 1988; Laycock, Crewther, & Crewther, 2007). This interaction seems to be also implicated in the fastest global analysis of the stimuli related to initiation of attention mechanism (Saalmann, Pigarev, & Vidyasagar, 2007).

Neuro anatomical studies demonstrated that in human and primate visual system, the visual information, runs segregated in two major pathways: Dorsal stream and Ventral stream (Merigan & Maunsell, 1993; Braddick & Atkinson, 2011) (Fig. 1). This segregation starts from the retina, continues to the lateral geniculate nucleus (LGN) in the thalamus, and to the primary visual cortex

(V1) (Casagrande, Yazar, Jones, & Ding, 2007; Merigan & Maunsell, 1993). The LGN is constituted by six layers: the two lower layers composed by magno-cells (M), and the other four upper layers by the parvo-cells (P) (Maunsell et al., 1999). The M and P cells differ in their anatomical and functional characteristics: M cells have larger receptive fields, higher temporal resolution and lower spatial resolution than P cells (Kaplan, 2004). The M cells provide the information about the changes and movements of the stimuli. From V1 this type of information is primarily transmitted to V2 and V3 and then coded in V5 (also called MT). From V5 this information is then transmitted to the posterior parietal lobe, constituting the dorsal visual stream. P cells instead are more sensitive to colors and stationary stimuli. From V1 this type of information is primarily transmitted to V2 and V3 and then coded in V4 and eventually transmitted to the infero-temporal areas, constituting the ventral visual stream (Livingstone & Hubel, 1987; Maunsell, 1987; Zeki, 1978).

Goodale and Milner (1992) proposed the perception-action model of primate vision, that provides a functional interpretation for the two cortical visual streams: ventral stream processes visual information for perceptual purposes (called what stream), and the dorsal stream provides visual guidance for movement (where stream). Even if there is a lot of evidence that ventral stream is implicated in form processing and dorsal stream in motion processing, latter studies show that the two pathways are not completely segregated. Conversely, the two streams show reciprocal cross-talks, mainly at intermediate levels (Merigan & Maunsell, 1993; Braddick, O'Brien, Wattam-Bell, Atkinson, & Turner, 2000; Keizer, Colzato, & Hommel, 2008).

The last 25 years had seen a huge increase in the number of publication concerning the development of the higher functions of the human visual system. In this period, the characteristic aspects of the primary visual cortex (V1), as orientation and direction selectivity, had been deeply investigated (e.g. Slater, Morrison and Rose, 1988; Hood, Atkinson, Braddick, and Wattam-Bell, 1992; Nothdurft, 1993). Further attention had been dedicated to the developing interactions between cortical and subcortical systems. In the last years increasing attention had been focused on the development of integrative functions linked to the extra-striate visual areas (e.g. Orban, 2008; Wattam-Bell et al., 2010; Skoczenski and Norcia, 2002; Allen et al.., 2009). Several studies had been conducted concerning hyperacuity, texture segmentation, grouping, optical illusions, global form and global motion sensitivity (for a review see Braddick and Atkinson, 2011).

Dorsal and Ventral functionality has often been assessed using psychophysical methods which simply test the functions which are supposed to be processed by them (Stein, 2003).

In former literature, different psychophysical methods and several tasks have been proposed to specifically activate dorsal or Ventral stream circuits. The application and validity of these tests and methods was assessed in healthy and clinical population.

Currently there is still a debate concerning the methods used to measure dorsal and ventral stream functionality. Motion and form perception are considered the golden standard measure for this purpose. The main criticism concerns the cross-talk between the two systems strong and their interactions with other cognitive functions such as general intelligence and visuo-spatial attention.

1.1.1 **Ventral stream tasks**

Several behavioral tasks have been proposed in former literature in order to specifically elicit ventral stream. The majority of the methods are based on form recognition.

One of the first task proposed was based on Glass Patterns stimuli. Glass stimulus, which was used for the first time in 1969 was composed by the overlap of two concentric circles. When a pattern of random dots is superimposed over an identical pattern and rotated a critical amount about the central axis, a compelling perception of concentric swirls arises. This kind of stimulus is still used in order to investigate the form perception (Ostwald, Lam, Li & Kourtzi, 2008); however, the perception of this stimulus involves high-level integrative processing of complex object (Grinter, Maybery, Pellicano, Badcock, & Badcock, 2010). For this reason, Glass Patterns couldn't be considered as an efficacy measure of the ventral functionality for itself.

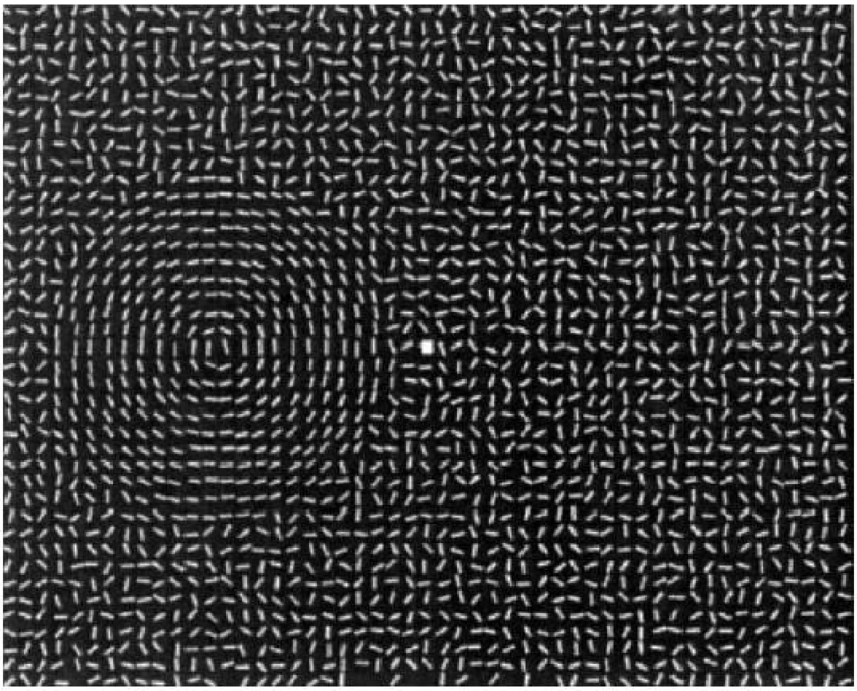

Figure 2 Atkinson and colleagues test

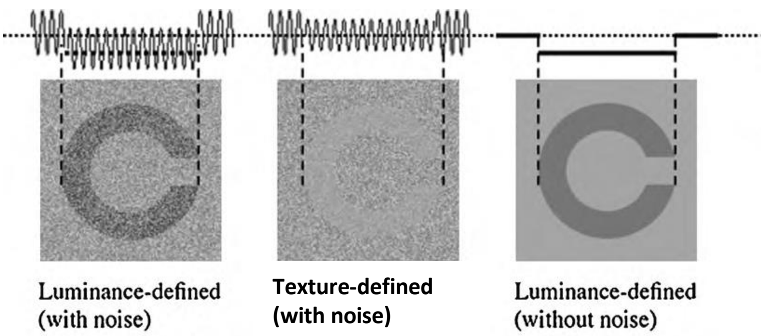

Figure 3 Landolt-C test

Figure 4 N-O-X test

The computerized test proposed by Atkinson et al. (2003, 2006) (Fig. 2), one of the most commonly used in literature, has some common elements with Glass Patterns (Wilson & Wilkinson, 1998; Braddick et al., 2000). The test is composed by a static array of randomly oriented short line segments with a target area on one side of the display where segments are oriented tangentially to concentric circles. The proportion of tangentially oriented ('coherent') line segments compared to the randomly oriented noise segments in the target area defines the coherence value for a given trial. Participants are asked to indicate if the target stimulus is present on the right or on the left side of the display. The Stimulus remains on the screen until the subject responds. The presentation follows a staircase procedure in which, coherence decreases stepwise of 0.84 until an error is made; the coherence is increased by 1/0.84 whenever an error is made and decreased by a factor 0.84 following two successive correct responses. Staircase procedure is followed until 6 reversal is done and the threshold is taken as the mean coherence level of the last four reversal points. In order to maintain the motivation of the subject every 4 stimuli, a 100% coherence one is show. These stimuli are not considered for the thresholds computation. Subject performance estimates with Atkinson et al. (2006) test presents however some criticism. Even if the use of the Staircase procedure could be considered a valid technique to determine the perceptive thresholds, the use of a forced choice between two possibilities significantly enhances the possibility to give the correct answer. A chance level of 50% represents an important limitation, especially if used on clinical and child population, that requires a high accuracy to determine the perceptive thresholds.

A modified version of Landolt-C stimulus (Landolt, 1905) (Fig. 3) was proposed by Bertone, Hanck, Guy and Cornish (2010). Target stimulus is constituted by a "C" that could be presented in 4 different spatial orientation. Different C-optotypes are presented, and participants are asked to verbally identify the orientation of the gap opening (up, down, left or right) after each trial. Practice trials are completed to familiarize participants with fixation, stimuli presentation and responding. An adaptive staircase procedure, as descripted above, is used to determine the perceptive threshold. Form perception thresholds are determined for 3 conditions. The first one luminance-defined in which the optotypes's form is defined by the difference in average luminance between the noise defining the optotype's form and that of its surrounding background. The second one texture defined, in which the contrast of the noise defining the optotype's form is varied, resulting in a form defined by the difference in contrast of the noise defining its form and that of its background. The third one, or control condition, constructed without the use of noise.

Landolt-C procedure allows to determine form perception thresholds by manipulation of luminance contrast. However, contrast-response functions of the magnocellular and parvocellular neurons are not unique; so apparently magnocellular and parvocellular responses can't be exactly identified on the basis of contrast, in particular for medium levels (2%-10%) (Skottun & Skoyles, 2011). Moreover, even if the chance level of 25% of this test is lower than in previous instruments, it could still be considered relevant when an accurate evaluation of sensitivity is need.

Another procedure, developed to assess apperceptive agnosia is called N-O-X test (Warrington & Taylor, 1973; Warrington & James, 1988) (Fig. 4). This instrument is composed by three conditions: one in which the letter "N" is presented, one in which the letter "O" is presented and a condition in which no form is presented (noise condition). Presented stimuli are made by superimposing a fragmented letter (either O or X) upon a fragmented background. The test stimuli are graded in difficulty by varying the ratio of black to white in the figure in relation to the ratio of black/white in the background. Subjects are asked to detect the presence of the letter and if is a N or O. The discrimination ability is determined by the number of correct answers (Warrington & Taylor, 1973). Even if N-O-X test efficiently determines the presence of apperceptive agnosia, it appears to be inefficient to evaluate subject's thresholds, evidencing a prominent ceiling effect. Furthermore, this test doesn't take into account the effect of the background noise on the degradation of the stimulus. In fact, it considers only the number of correct answers to estimate the subject ability. Also for this test the chance level results fairly high, with a 33% of correct answers by chance. Moreover, the very large dimension of stimulus dots could determine the elicitation of both visual streams. Ventral stream, in fact, is implied in perception of the details. The use of large stimulus could determine also an activation of dorsal visual processes (Bruce, Green, & Georgeson, 2003).

1.1.2 Dorsal stream tasks

In order to assess dorsal pathway different type of moving stimuli have been used.

Studies in literature showed that early stages of motion detection operate over small regions of space. This creates ambiguity about the true direction of motion of an object or display occupying a larger region, ambiguity that is exemplified in the well-known aperture problem. To determine the overall direction of motion, the outputs of local motion detectors must be integrated over space and time (Smith, Snowden & Milne, 1994). Several evidences indicated that cells in the primary visual cortex (V1) are responsible to detect the direction of motion in local regions of the visual field and that cells in the middle temporal area (MT), that have much larger receptive fields, integrate those signals over both space and time to give rise to the perception of global motion (O'Keefe & Movshon, 1998; Sekuler, 1992).

Motion perception has been modeled as hierarchically organized in different systems from the very early theory of motion perception (Boring, 1942). Lu ad Sperling (1995) proposed a model of motion perception as served by three systems: first, second and third order motion system (see for a review Lu and Sperling, 2001; see also Nishida, 2011; Burr & Thompson, 2011). While in first order motion the changes in boundaries are defined by luminance levels; in second order motion tests the motion is defined by other cues, like contrast or texture. Third order motion system is linked to 3-D motion perception or biological motion perception, and allows to compute the motion of marked locations in a ''salience map,'' in which the motion signal is differentiated from the background.

Several evidences suggest that the neural mechanisms that process first, second and third order motion are processed separately (see Nishida, 2011 for a review). Both first and second order motion could be either local or global. Local stimulus could be correctly analyzed by a single receptive field. Global motion instead needs the integration of multiple local motion signals to be correctly perceived (Armstrong, Mauerer, & Lewis, 2009). Sensitivity to local motion is commonly measured using contrast thresholds. This is defined as the minimum difference in luminance (for first-order stimuli) or contrast (for second-order stimuli) between adjacent stripes required for the observer to accurately discriminate direction of motion (Armstrong, Mauerer, & Lewis, 2009) (Fig. 6).

A gold standard test used in visual research in order to assess first order motion system is global or coherent motion test. Global motion stimuli consist of coherently moving dots on black background displayed on a computer screen. A proportion of dots move in one specific direction while some others move in a brownian manner (De Vries, 1948). The lifetime of each single dot is manipulated in order to avoid tracking (i.e. the dots temporal frequency is very high). Accordingly, the subject usually has to detect the dots which are moving coherently and therefore to discriminate their direction.

Numerous studies found that global motion processing is better under binocular viewing (Hess, Hutchinson, Ledgeway, & Mansouri, 2007), invariant with retinal eccentricity (Hess & Aaen-Stockdale, 2008) and invariant with mean luminance (Hess & Zaharia, 2010) (for a review see Nischida, 2011).

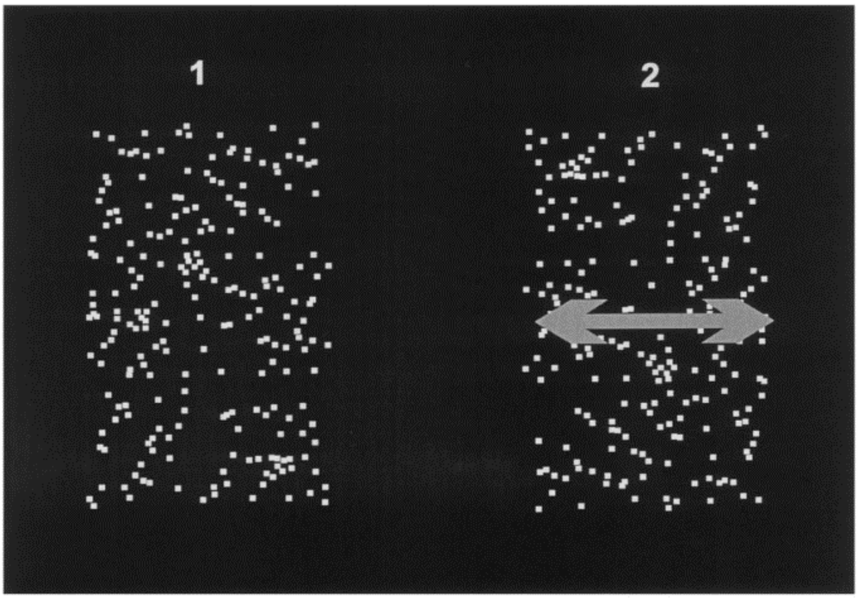

Figure 5 Cornelissen test

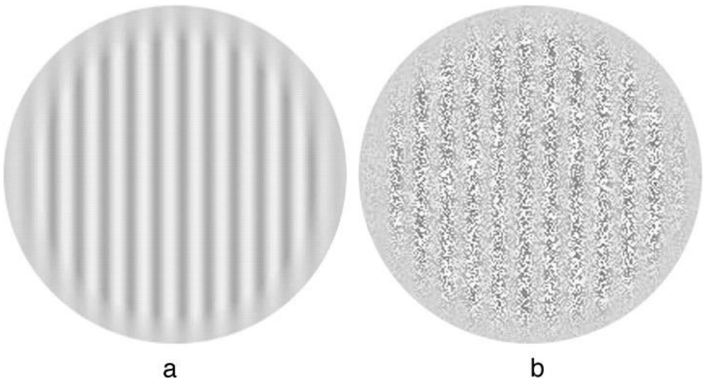

Figure 6 Armstrong and Maurer test

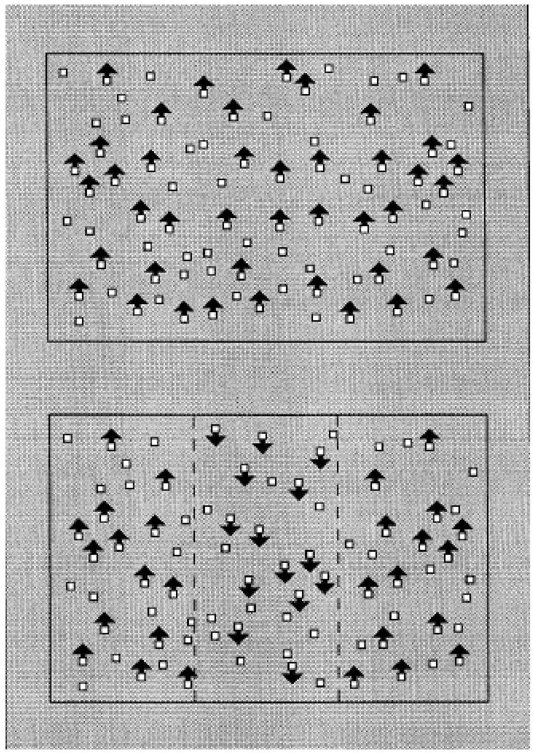

Figure 7 Atkinson and colleagues test

Several versions of this task were created by different authors. In the most part of these tasks (Cornelissen, Hansen, Hutton, Evangelinou, & Stein, 1998; Fig. 5; Levy, Walsh, & Lavidor, 2010; Hansen, Stein, Orde, Winter, & Talcott, 2001) two stimuli are presented: one displaying dots with coherent motion and the other one displaying random motion dots. Subject is forced to choose between the two possibilities by indicating in which one the coherent motion is presented. A staircase procedure is adopted to determine the perceptive threshold. In order to avoid the possible strategy of subjects looking constantly at one of the hemifield, Levy et al. (2010) proposed a modified version of coherent motion task in which an additional condition with no coherent motion was added. Atkinson et al. (2006) (Fig. 7) proposed a version of coherent motion task in which the stimulus comprised two random dot kinematograms (white dots on a black background), one at each side of a central vertical strip. The pattern on one side is divided into three horizontal strips, such that the direction of the coherent motion of the middle 'target' strip is opposite to that of the two outer strips. The dot array on the opposite side of the screen display a uniform direction of motion consistent with the direction of the two outer strips. Thresholds are obtained by a two-alternative forced choice procedure. Participants are required to locate the target regions, which are presented randomly either in the left or the right half of the display. As previously described M-cells mainly respond to higher temporal lower spatial frequency while P-cells primary respond to lower temporal higher spatial frequency. As Skottun and Skoyles (2008) argued, spatial and temporal frequencies should be very carefully selected. Authors suggested that the difference in temporal properties between magno- and parvocellular neurons are relatively small; it appears that in order to achieve magnocellular selectivity it's necessary to use quite high temporal frequencies. Contrast sensitivity is indeed difficult to measure during childhood, in typically population, because it develops during early infancy but takes 7 years to reach adult levels.

Second order motion system is widely investigated by mean of texture moving stimuli. The use of contrast allows to modulate the temporal and spatial frequency of the moving stimuli. According to Lu and Sperling (2001), the signal to the second-order motion system is the modulation of texture contrast. An example of second order motion stimulus is a patch of a texture type which moves consistently from frame to frame, considering each patch as independent, uncorrelated sample. Starting from the first frame composed by side-by-side patches of right-slanting gratings disconnected from left-slanting gratings patches. The luminance and the overall contrast is maintained constant across patches. In a second frame, the patch pattern is moved sideways, and new patch samples are chosen (Fig. 8).

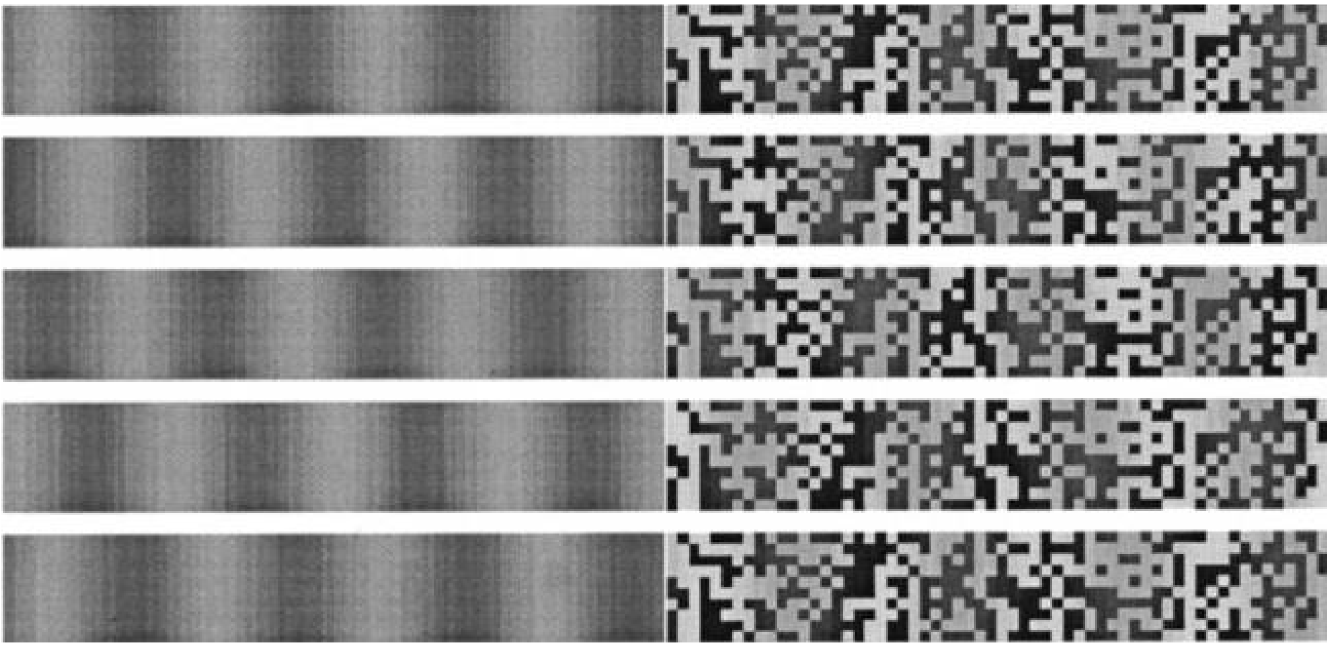

Figure 8 First order stimulus (left) and second order stimulus (right)

A specific kind of stimuli that have been widely used to test third order motion system is the biological motion (see Blake & Shiffrar, 2007 for a review). The majority of these studies employed point-light (PL) animations to isolate human kinematics, in order to study body movements in the absence of all other clues. With this technique, the activity of a human is displayed by the motion of a small number of markers positioned on the head and the joints of the body. Sensitivity to human motion increases with the number of illuminated joints and with the duration of the animation (Neri et al. 1998, Poom & Olsson 2002, Thornton et al. 1998). But even under impoverished or potentially ambiguous conditions, perception of human motion remain robust. The ability of recognizing human motion by point light animation has been evidenced early in life: infants already showed a preference for human motion sequences at 4 months of age (Bertenthal, 1993). Nevertheless, motion detection is fundamental for the analysis of biological motion, several studies showed that biological motion perception is influenced also by the form perception. Without the analysis of the structure of the human body, it would be almost impossible to segregate moving "body" dots from moving "noise" dots (Pinto & Shiffrar 1999).

Another task designed to evaluate the dorsal stream functionality is the speed discrimination. This instrument usually involves a two-interval forced choices. The subjects' task is to report which of the two stimuli moved faster (Demb, Boynton, Best, & Heeger, 1998). However, some studies further suggest that speed and direction may be separately processed in the brain (Saffell & Matthews, 2003; Brouwer, Brenner, & Smeets, 2002).

Even if a number of studies (e.g. Cornelissen et al., 1998; Edwards et al., 2004; Milne et al., 2002; Pammer & Wheatley, 2001; Schulte-Korne, Bartling, Deimel, & Remschmidt, 2004; Stein, 2003; Talcott, Hansen, Assuko, & Stein, 2000) suggested that perception of coherent motion can be used to assess the sensitivity of the magnocellular system, some criticism has been reported. Skottun and Skoyles (2006), argued that coherent motion perception would be an indirect test, mediated via area MT, of magnocellular sensitivity. Furthermore, the authors underline that MT area receives its input mainly but not exclusively from the magnocellular system. Parvocellular system also contributes input to this cortical area (Maunsell, Nealey, & DePriest, 1990; Merigan & Maunsell, 1993; Sincich & Horton, 2002; Yabuta, Sawatari, & Callaway, 2001), suggesting a possible influence of Parvocellular neurons on MT. Furthermore, as found by Pilly & Seitz (2009), the different algorithms used to generate the stimulus influence the detection thresholds. So, it appears difficult to make direct comparisons across studies employing different RDK algorithms.

1.2 **Estimating thresholds**

Together with the development of the techniques to measure the perceptual phenomena, the problem of defining thresholds was carried on together with the development of psychophysics. This issue started from Fechner (1860) that developed the classical psychophysical methods for estimating the difference threshold. The threshold is considered to be the stimulus difference that can be discriminated in some fixed percentage of the presentations (e.g. 75%), so the goal of a threshold experiment is to find a level of the stimulus that leads to a preselected level of correct answer.

Anyway, an empirical threshold is a statistic, an estimate of a theoretical parameter, in any experiment is impossible to determine its real value. The threshold is a function of the data, a measure that depends on the results of a set of trials. Estimating thresholds should be evaluated in terms of costs and benefits. The costs are represented by the time spent by the experimenter and the subjects in order to achieve a good level of accuracy (Treutwein, 1995). Classical psychophysical conceptualization identifies different approaches in order to estimate thresholds:

- The method of constant stimuli: a number of suitably located points in the physical stimulus domain are chosen. These stimuli are repeatedly presented to the subject together with a comparison or standard stimulus. The cumulative responses (different or same) are used to estimate points on the psychometric function, i.e. the function describing the probability that the subject is judging the stimulus as exceeding the standard stimulus.
- The method of limits: the experimenter varies the value of the stimulus in small ascending or descending steps starting and reversing the sequence at the upper and lower limit of a predefined interval. At each step the subject reports whether the stimulus appears smaller than, equal to or larger than the standard.
- The method of adjustment is quite similar to the method of limits and is only applicable when the stimulus can be varied quasi-continuously. The subject adjusts the value of the stimulus and sets it to apparent equality with the standard. Repeated applications of this procedure yield an empirical distribution of the stimulus values with apparent equality which is used to calculate the point of subjective equivalence (PSE) (Treutwein, 1995; Purghè, 1997).

The main difference of the adaptive procedure as compared to the classical ones is that the stimulus values are not completely defined before the experiment but varies subsequently to the response (correct or not) of the subject. A typical adaptive procedure that is commonly used in vision perception studies is the staircase procedure (Ellemberg 2004; Armstrong & Maurer 2009; Hadad, Maurer & Lewis, 2011; Harvey, 1986). The goal of this procedure is to change the stimulus during the course of the trials to converge on that stimulus giving the desired performance level. Running staircase procedure after each trial the stimulus value is changed by a fixed the step size. If a shift in the response category occurs (from success to failure or vice versa), the direction of steps is changed. This procedure is valid for every sequence of presentation. The final estimate is obtained by averaging the reversal point (Treutwein, 1995). Staircase methods doesn't require any assumptions about psychometric function that better describes the phenomenon. Staircase require only to define the momentum when the stimulus level will change and what kind of step has to be used. A limitation of this method concern the unequal number of stimulus presentation and stimulus level for each subject. Moreover, there is no clear statistically determined basis for stopping or for calculating a threshold value from the results of trials. To respond to these limitations, a variation of this technique is called "the up-down transformed-response" (UDTR) method by Levitt (1970). Levitt suggested that the changes of the stimulus value depend on the outcome of two or more preceding trials. For example, the level is increased with each incorrect response and decreased only after two successive correct responses (1-up/2-down, or 2-step rule) (Treutwein, 1995).

1.2.1 The Signal Detection Theory

A different conceptualization of the decision-making process is the Signal Detection Theory (SDT). This approach had been originally developed in communications engineering to be employed in electronical receiving entity (e.g. a radar). Afterwards this framework had been used in psychology in opposition with classical psychophysical approach (Purghè, 1997). The main aspect of this framework is to shift the attention from the classical concept of sensory thresholds to the decision-making processes. The observer has to decide if the stimulus is present or not on a continuum. The SDT consider the contribution on the decision of two different contributions: the individual sensitivity, that is an implicit characteristic of the perceptive system and the response criterion, that is related to the observer, and is influenced by different aspects, as intrinsic motivation and rewards (Purghè, 1997). The TSD approach assumes the perception as a continuous variable. An observer who is trying to distinguish two stimulus types, for example Signal and Noise, needs to evaluate the distributions of values for each possibility. Errors arise because the Signal and Noise distributions overlap, and the degree of overlap is an inverse measure of accuracy, or sensitivity. Improvements in sensitivity can only occur if this overlap is reduced, and such reductions are often not under the immediate control of the observer (Wixted, 2004). The sensitivity index d' expresses the ratio of overlap of the two distributions. In each YES-NO design experiment, the decision-making process could provide four different outcomes: a true positive, a false positive, a true negative and a false negative (Fig. 9). Different criteria and different sensitivities could origin different proportion of this responses. The Neyman Pearson Objective (Treisman & Watts, 1966) postulate that the observer bases his decision on the evaluation of the hit rate (the true positive) and the false alarm (false positive), operating an estimation of the two distributions. The payoff matrices could influence the importance that the subject give to the hit rate or the false alarm, maximizing one at the expense of the other.

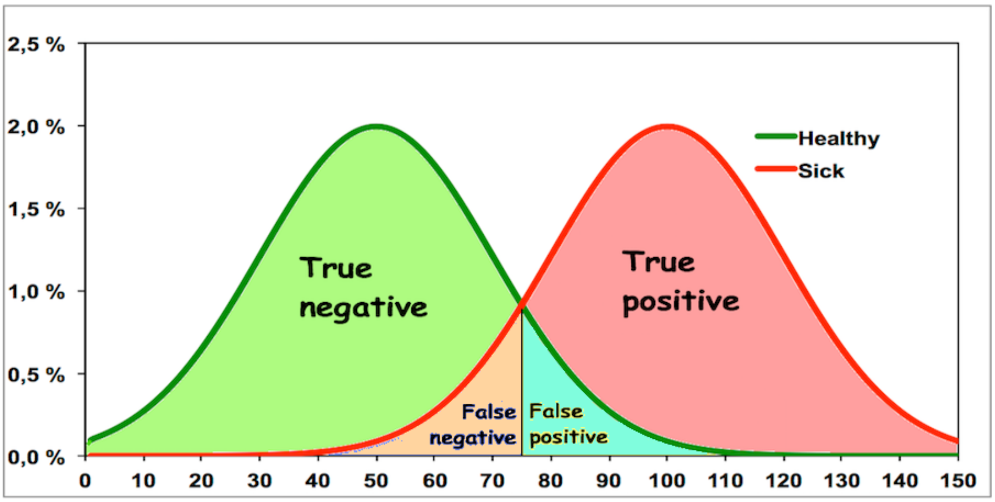

Figure 9 Distributions of positive and negative responses in decision making process

The information resulting from an experiment using the SDT paradigm could be summarized using a graphical representation of the proportion of the hit and of the false alarm. This kind of representation, originally developed during the II World War for the analysis of radar images is called Receiver Operating Characteristics (ROC) curves (Fig. 10). The ROC curves display on the Y axis the Sensitivity index, defined as the number of true positive decisions/the number of positive cases and on X axis 1-Specificity, that is defined as number of true negative decisions/the number of negative cases. The best possible decision would create a line yielding in the upper left corner, representing 100% sensitivity and specificity. A random classification would give a line along the diagonal line (Purghè, 1997, Bottarelli and Parodi, 2003).

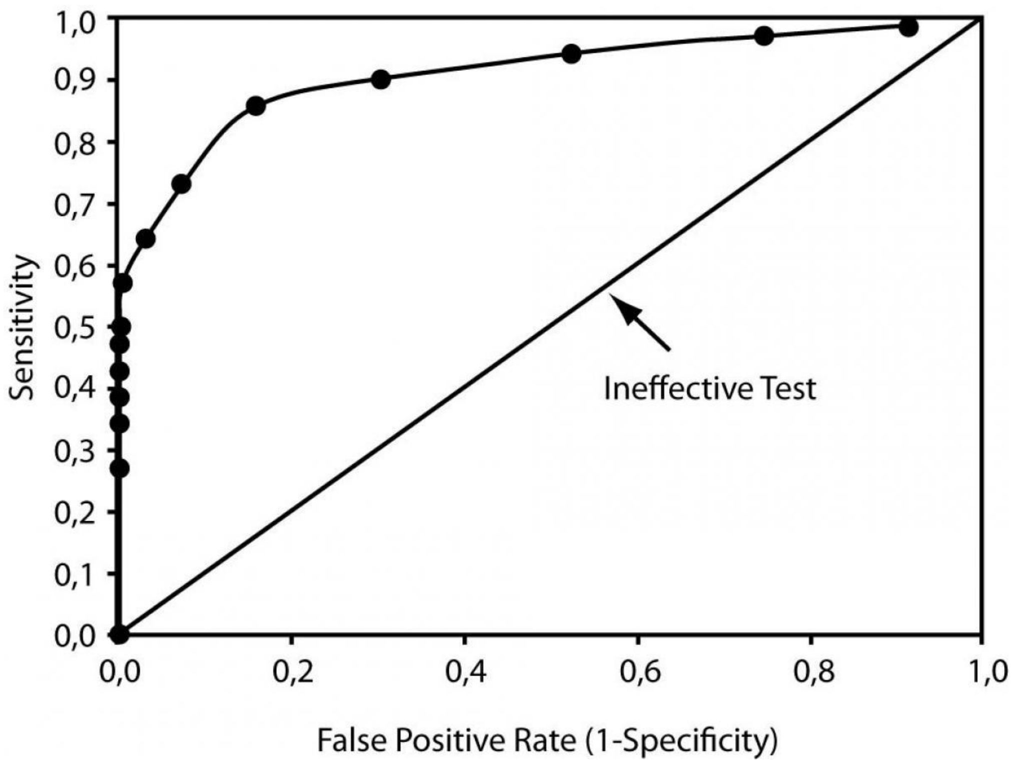

Figure 10 A Receiver Operating Characteristics (ROC) curve

1.2.2 **Psychometric Functions**

A psychometric function relates some physical measure of stimulus to some performance measure of detection or discrimination, such as hit rate, percent correct, or d' (Torgerson, 1958) (Fig 11). When performance is expressed as probability, psychometric functions typically are S-shaped in form. Since it is not a priori obvious which analytical function will fit any given set of data best, one needs to do these estimates by using different analytical functions. A general way to describe a psychometric function is

$$P_C(\xi) = \gamma + (1 - \gamma - \lambda)\Phi(\xi),$$

where $P_C = P$ is the proportion of correct response (usually showed ad ordinate), ξ is a measure of the stimulus level, γ is the guessing rate or chance level, equal to 1/n for a n-alternative forced choice task, and λ is the lapsing rate, which describes non-perfect performance and that is usually set to 0 for simplicity. Threshold level, usually indicated by α, determines the function's horizontal position.

This level is definite in several different ways. One of them is the x coordinate of the point "halfway up" that could be calculated as

$$P_C = \gamma + (1 - \gamma - \lambda) / 2.$$

In literature, it is frequent to use also another criterion level for the definition of the threshold. The threshold is defined as the point of maximum inflection (i.e. the maximum slope, when the curvature changes its acceleration) or, more commonly, the stimulus level that can be discriminated at a fixed level of accuracy, e.g. 75% (Strasburger, 2001; Treutwein, 1995).

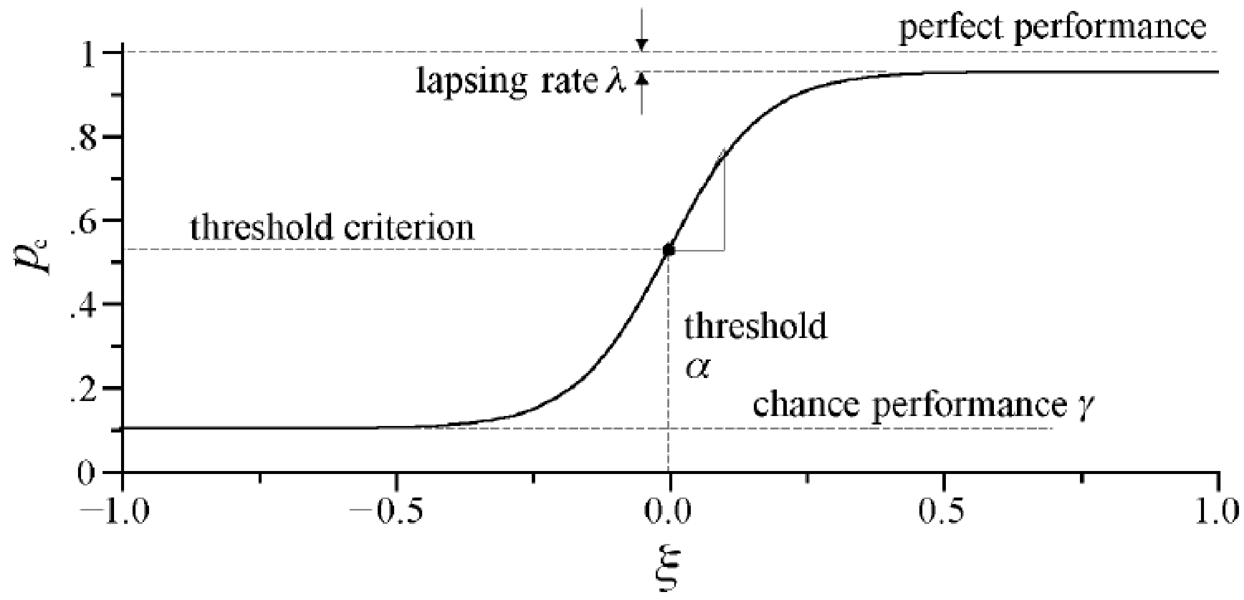

Figure 11 - Psychometric function

Fitting psychometric functions could be considered a three-steps process. As a first step, the model selection has theoretical and mathematical basis, and the parameters are adjusted to minimize the appropriate error metric or loss function. As a second step, the error estimates of the parameters are derived; finally, the evaluation of the goodness of fit, attesting the accuracy of the adopted model to represent the data (Wichmann & Hill, 2001).

There are a large number of probabilistic functions that can be used to characterize the subjects' performance. The use of specific functions has to be theoretically justified. Furthermore, the function has to be selected for its simplicity. The simplicity of the function is related to the number of the parameters (that should be as small as possible). The more parameters are to be estimated, the more trials are necessary for an accurate estimation (Treutwein, 1995). Since is not always possible to determine a priori which analytical function will be the best for fitting experimental data, it is necessary to compare the solutions obtained by different functions.

Parameter estimation consists of finding the parameter values of a probability function that best represents the distribution of the empirical data. This process is usually conducted by an iterative approach. This approach allows to estimate the parameter values that best fit a frequency distribution with progressive approximations (i.e. iteration), proceeding step by step until the estimated value converge to the final solution. To do this, the fit of the probability function to the data is evaluated using a goodness of fit (or error) criterion. Typically, the procedure involves changes in parameter values that are made smaller at each iteration until the adjustment yields only small changes in the fit criterion. The search stops either when the improvement in fit is smaller than a pre-determined criterion or when the change in parameter values is smaller than another pre-determined value. The stopping criteria are called tolerances. The procedure reaches convergence criterion when the improvement in the goodness of fit is smaller than the termination tolerance or when the change in parameter values is smaller than the function tolerance (Lacouture, 2008). The parameter search may fail to converge. This occurs when, after performing many iterations, the change in the fit criterion at a given iteration does not become smaller than the value of the termination tolerance or when the change in parameter values does not become smaller than the function tolerance. In this case, a good alternative strategies could be to start the search process with appropriate parameter values (i.e. close to the real parameter values), or to increase the maximum number of iterations allowed for the search process, or, finally, to increase tolerances of the parameter estimation (Lacouture 2008). This process could be conducted by using the nonlinear least-squares formulation. This technique shares some similarities to linear least squares (used in linear regression analysis), but also significant differences. Nonlinear models are more difficult to fit than linear models because the coefficients cannot be estimated using simple matrix techniques. Instead, an iterative approach is required. In the iterative approach the fitting starts with an initial estimate for each coefficient, then it produces the fitted curve for the current set of coefficients and, using a fitting algorithm, it adjusts the coefficients and determines whether the fit improves. This process will iterate, by producing a new curve, until the fit reaches the specified convergence criteria.

A different technique, that is widely used, is the maximum likelihood estimation. The basic idea of the method of maximum likelihood is given by the following consideration. Different populations generate different data samples and any given data sample is more likely to come from one population than from others. The method of maximum likelihood is based on the principle that we should estimate the parameter vector, which describes the psychometric function, by its most plausible values, given the observed sample vector (Treuwein, 1995). The likelihood function represents the likelihood of the parameters given the observed data; finding the probability density function, among all the probability densities that the model prescribes, that is most likely to have produced the data. The principle of maximum likelihood estimation (MLE), originally developed by Fisher in the 1920s, seeks the probability distribution that makes the observed data most likely (Myung, 2003).

1.3 **Aims**

The research focuses on the study of the methods useful to evaluate the developmental trajectories for motion perception and form perception. The presented studies aim to analyze the psychometric characteristics of two tasks created for measuring the functionalities of the dorsal and the ventral streams: the coherent motion test for measuring motion perception, an ability processed mainly by the dorsal stream, and the coherent form test to measure form perception abilities, an ability processed mainly by the ventral stream.

The first study aims to present the Motion coherence test and Form coherence test as new tools to investigate motion and form perception accuracy. The use of these tests will allow to handle with some of the methodological criticisms reported in other studies (i.e. the use of contrast based task to assess dorsal functionality and the high chance level). The tests have been assessed in a large sample of children of different ages.

The second study aims to evaluate the applicability of a specific psychophysical function which allows to analyze the accuracy profiles obtained both by motion and form coherence test. The response profiles of each of the two tasks will be fitted with an appropriate psychophysical function, that estimates the subject's accuracy performance (i.e. the mean number of correct responses) on the basis of the coherence level of the stimulus. Moreover, the use of the proposed function allows to statistically define the perceptive thresholds of the two tests and to compare them.

The third study aims to analyze the developmental trajectories of dorsal and ventral streams in a sample of typically developing children and adults recruited in two European countries (Italy and Sweden). Secondly, in this study the normative scores for motion coherence and form coherence tests are given on the basis of different group of ages.

The aim of the fifth study is to evaluate if motion and form test could be useful to recognize specific deficits in clinical population. The differences between motion and form perception accuracy is evaluated in children with different genetic syndromes (Noonan syndrome and 22q11.2 deletion syndrome) and compared to controls.

2. Experiment 1 – Methods for the assessment of motion and form perception abilities in school-aged children

A large body of studies concerning the role of vision functions in human cognitive development is present in current literature (see Braddick & Atkinson, 2011). Several neuroanatomical and neuropsychological studies point out that the visual information runs segregated in two major pathways: dorsal and ventral streams (Merigan & Maunsell, 1993; Braddick & Atkinson, 2011). These visual streams present specific anatomical and functional characteristics. Goodale and Milner (1992) proposed the perception-action model of primate vision, that provides a functional interpretation for the two cortical visual streams: ventral stream processes visual information for perceptual purposes (called *what* stream), and the dorsal stream provides visual guidance for movement (*where* stream).

The analysis of the functionalities of the two visual systems, was conducted on different populations (both clinical and not), by means of paper and pencil or computer based visual stimuli. Nevertheless, some authors argued that the methods and the tasks used in order to elicit dorsal and ventral streams present several methodological criticisms (see Skottun & Skoyles, 2008 for review).

The processing of motion is a critical part of visual perception. It is necessary, in everyday life, to track moving objects with eyes, to reach and grasp them and to navigate in a dynamic world. In order to accomplish to this finality, it is often important the ability to combine the motion information of an object within the surrounding space. This ability is called *global motion processing* and it is commonly tested using motion coherence paradigm (Manning, 2014). The Random dot kinematograms (RDKs) represents in fact a gold standard, used by different authors, useful to elicit dorsal stream functionality (e.g. Cornelissen, Hansen, Hutton, Evangelinou, & Stein, 1998; Levy, Walsh, & Lavidor, 2010; Hansen, Stein, Orde, Winter, & Talcott, 2001). This kind of test consists of signal luminance dots moving coherently in one direction and luminance noise dots that move in random directions. The subject is usually asked to identify the coherent motion or its overall direction.

Concerning the Ventral stream, the analysis of the literature shows, in particular for children and adolescents populations, a limited number of instruments suitable for the assessment of form perception. Furthermore, the comparison between the results of studies with different population and with different instruments it is not always possible. Some of the tests that are present in literature require the recognition of a form that consist of a single element, while in others the form is constituted by several components. This kind of perception is based on the ability of the visual system to integrate the information of the elements that compose the stimulus. The parts of stimuli that together constitute a pattern or shape are sometimes called "coherent". Coherency can be characterized by different characteristics, such as the direction of the movement, the orientation, the contrast in brightness or color. The characteristics of the stimulus determine the coherency, allowing the visual information integration process and the subsequent recognition of the shape. A kind of coherency that has been widely applied in the form perception studies is the spatial coherence. Several studies showed that human visual system can perceive a series of spatially aligned stimuli (spatial coherence) as bi or three-dimensional object with a recognizable form (Atkinson , Braddick, Nokes, Anker and Braddick, 1997; Atkinson, Braddick, Rose, Searcy, Wattam-Bell and Bellugi, 2006).

One of the most commonly instrument used in literature based on spatial coherency is the one developed by Atkinson and colleagues (2000, 2006). The stimulus was composed by a static array of randomly oriented short line segments, containing a ‘target’ area on one side of the display where segments were oriented tangentially to concentric circles. The proportion of tangentially oriented (i.e. coherent) line segments amongst the randomly oriented ‘noise’ segments in the target area defined the coherence value for a given trial. Thresholds were obtained by a two-alternative forced choice procedure. Participants were required to locate the target regions, which were presented randomly either in the left or the right half of the display. In each task, the initial coherence level was set to

100%. The percentage of coherence was decreased stepwise on each trial by a factor of 0.84 until an error was made; following this the coherence was increased by 1/0.84 whenever an error was made and decreased by a factor 0.84 following two successive correct responses. The staircase procedure was followed until six reversals had occurred, and the threshold was taken as the mean coherence level of the last four reversal points.

The stimuli developed for the evaluation of the form and motion perception ability, present some methodological limitations (Grinter et al., 2010). In particular, the calculation of the threshold for visual perception of the motion and shapes requires the administration of numerous trials. The subject is asked to identify the target stimulus through the comparison with another stimulus (2 alternative forced choice). This procedure requires for the completion a protracted commitment of the subject. The performance could be consequently affected by the oscillations of the attentional threshold and by the effects of fatigue. These two limitations could be particularly salient in children and adolescents. Furthermore, in some form tests (e.g. Atkinson et al., 2000) the request to locate the target regions in which the target stimulus was presented could be considered an explicit "where" task; while the recognition of the stimulus represented in this test an implicit "what" task.

2.1 **Aim**

The aim of this study is to evaluate the psychometric properties of the Motion and Form Coherence test in a population of typically developing children. These tests were specifically developed to measure the ability to discriminate the motion direction and the forms from the background noise. In order to cope with some of the criticism emerged from the tests already present in the literature; the Form coherence test use the technique of signal consistency (i.e. the percentage of correctly aligned dots).

Furthermore, in order to avoid the problems derived from the use of the brightness contrast (Skottun, 2000) and to verify in a suitable way the performance of the parvo-ventral system, the instrument presented explicitly requires the subject to make a ventral task. The subject was requested to indicate what form did he/she see. This procedure would characterize the task presented as explicit evidence of visual discrimination of form, differing from other tests in the literature that require recognition in a more implicit way (to the subjects are asked to indicate between two stimuli "which is the form"). The presented tests also attempted to cope with the high chance level that characterize some of the previous test. The 8-alternative forced choice place the chance level at 12.5%. Finally, the presence of different levels of difficulty, allows a good accuracy in the evaluation of motion and form discrimination and deals with the ceiling effect that characterizes some of the instruments used in the literature.

2.2 **Methods**

2.2.1 **Participants**

The sample was composed by 250 children aged 5 to 12 years old. One-hundred-twenty-seven of them was males (mean= 7.8; SD= 2.0) and 123 females (mean= 8.1; SD= 2.2). For each subject a proper informed consent was obtained for both parents. A sample of 75 children (36 Female; age range: 5.2 – 12.4; mean age = 6.7 years) was selected in order to evaluate criterion validity. Furthermore, a subsample of sample of 51 subjects (20 female; age range 8-11 years; mean age 9.3) repeated the tests in order to evaluate the reliability. The participants had been selected from general population by recruiting them during school typical assessment. No one had sensory deficit or neurological disorder.

All of the children presented a normal level of general intelligence (QI above 85), measured using the Raven's Colored Progressive Matrices (Raven, 1992). All of the subject presented a normal or corrected to normal visual acuity evaluated by LEA vision test (Repka, 2002) by orthoptists.

2.2.2 Measures and procedures

The tests are administered individually to the participants in one sessions of about 15-20 minutes. The presentation order is randomized. A psychologist is present for the whole experiment. A subsample of 51 children repeated the two tests after half an hour.

Raven's Colored Progressive Matrices (CPM):

The Raven's CPM (Raven, 1992) is a common measure of basic cognitive functioning, quantifying a child's ability to form comparisons and to reason by analogy (Raven, Raven, & Court, 1962). The test comprises 36 items divided into three sets of 12 (A, Ab and B) in which items are ordered by increasing difficulty. Each item is presented as a colored pattern with a missing portion and 6 options from which to choose to fill in the missing element. Some items test the ability to complete a continuing pattern. Others require perception of the parts of the whole pattern as one gestalt on the basis of spatial relations. Finally, some of them require analogical reasoning.

Motion coherence test:

Motion perception is evaluated with the Motion Coherence Test (Benassi, Rydberg, Belli, & Bolzani, 2003; Menghini et al., 2010) (Fig. 12), a computerized behavioral test designed to assess dorsal pathway functionality. On a black background (0.2 cd/m2), 150 high luminance dots (luminance 51.0 cd/m2) could move coherently at a constant speed (6.1°/s) in one of the eight directions of the space (4 cardinal and 4 oblique). Dots are displayed on a computer screen at a distance of 130cm from the participants and subtended a visual angle of 5°. To avoid the possibility of tracking, each dot has a limited lifetime of 4 animation frames (duration = 200 ms). The task consisted of 5 levels of difficulty (0 to 4), each one compose by 8 trials. Coherent motion percentage is defined as the number of dots in coherent motion on the total of dots. The non-coherent dots moved randomly between frames in a Brownian manner. Practice trials are completed to familiarize participants with fixation, stimuli presentation and responding. Starting from a condition of 100% coherence (all the dots moved coherently in one direction), at each step the noise (Brownian motion dots) increases of 2db (each level has a decrement of 37% of coherent dots as compared to former). Therefore, the difficulty increases in each level. Participants are asked to indicate the direction of the perceived motion by choosing between the 8 possible directions. The chance level is thus 12.5%, a lower level as compared with other instruments presented in literature. The subject's motion perception ability is calculated as the mean of the correct answer for each level. In addition, for each subject it will be possible to evaluate the percentage or the mean of the correct answer for each direction.

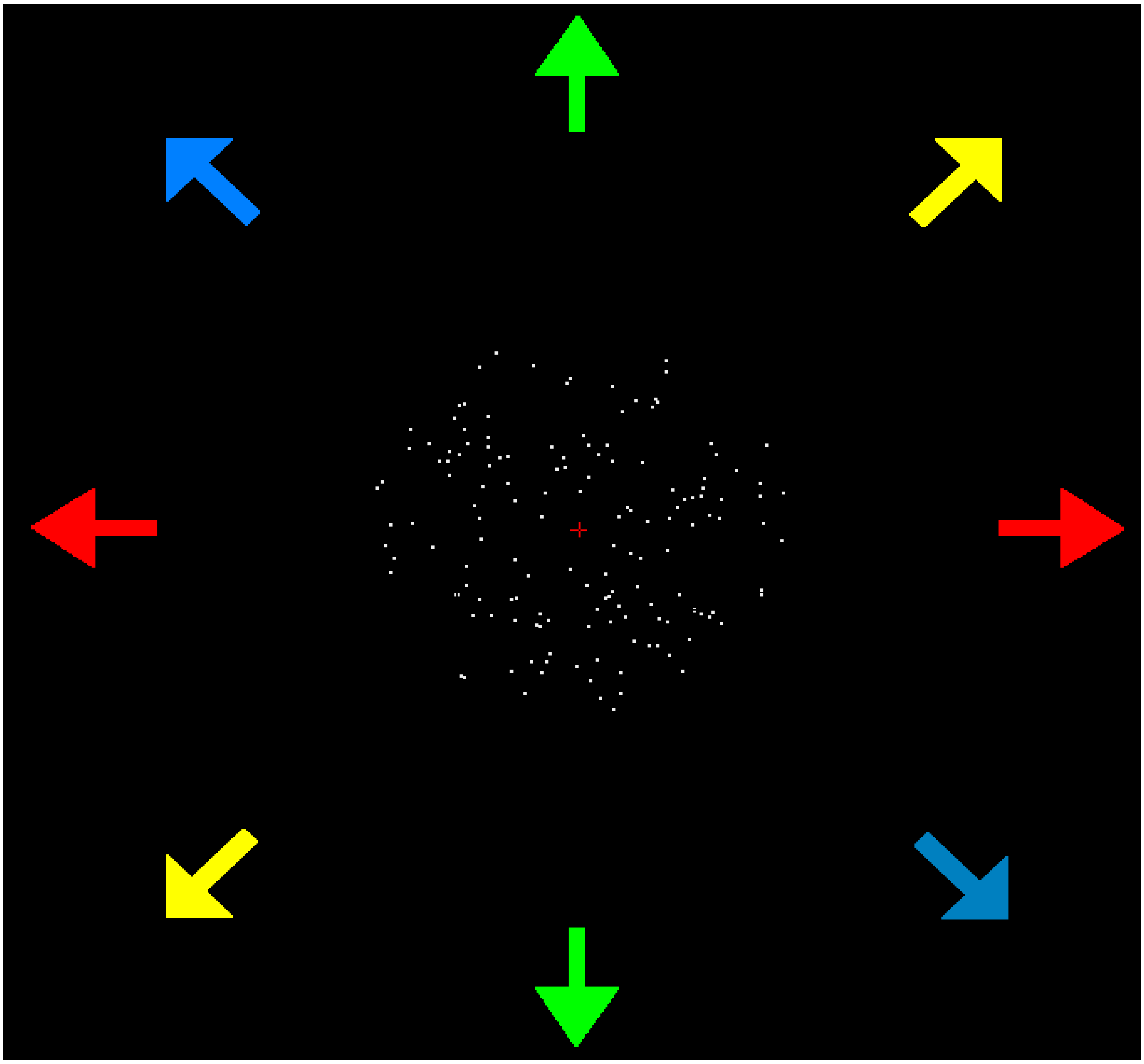

Figure 12 Motion coherence test

This kind of test is supposed to elicit the magnocellular system - dorsal pathway because it's based on high temporal frequency stimuli and the subject is asked to make a *where task*. The motion perception is allowed by the coherent motion stimuli that move as a group, for that reason the stimuli is considered global motion task. The motion is based on luminance level, thus it could be considered as a first order motion stimuli. This aspect could cope with the criticism reported by Skottun and Skoyles (2011) regarding the use of contrast sensitivity tasks in order to elicit magnocellular functionality.

Form Coherence Test:

Form perception is evaluated with the Form Coherence Test (Fig. 13). This computerized behavioral test is a new computer based tool designed to assess ventral pathway functionality. On a black background (0.2 cd/m2), 1962 static high luminance dots (luminance 51.0 cd/m2) are displayed at a distance of 130cm from the participants and subtended a visual angle of 5°. A part of the dots produce, with a coherent spatial continuity, one of the 8 possible forms: circle, square, triangle, star, house, doll, glass. The other dots, representing the background noise, are disposed randomly. Practice trials are completed to familiarize participants with fixation, stimuli presentation and responding. The task consisted of 5 levels of difficulty (0 to 4) each one composed by 8 trials. The coherence is defined as the number of spatially aligned dots on the total of dots presented in the frame. The noise is represented by dots that are randomly disposed in the frame. Starting from a condition of 100% coherence, at each step the noise increases of 3db (each level has a decrement of 50% of coherent dots compared to former). Therefore, the difficulty increases in each level. Participants are asked to indicate the correct form, choosing between the 8 possible forms. The chance level is thus 12.5%, a lower level as compared with other instruments presented in literature. The subject's form perception ability is calculated as the mean of the correct answer for each level. In addition, for each subject it will be possible to evaluate the percentage or the mean of the correct answer for each form. This kind of test is supposed to elicit the parvocellular system - ventral pathway because it's based on high spatial frequency stimuli and the subject is asked to make a *what task*. The use of luminance defined stimuli could cope with the criticism reported by Skottun and Skoyles (2011) regarding the use of contrast sensitivity tasks in order to elicit parvocellular functionality.

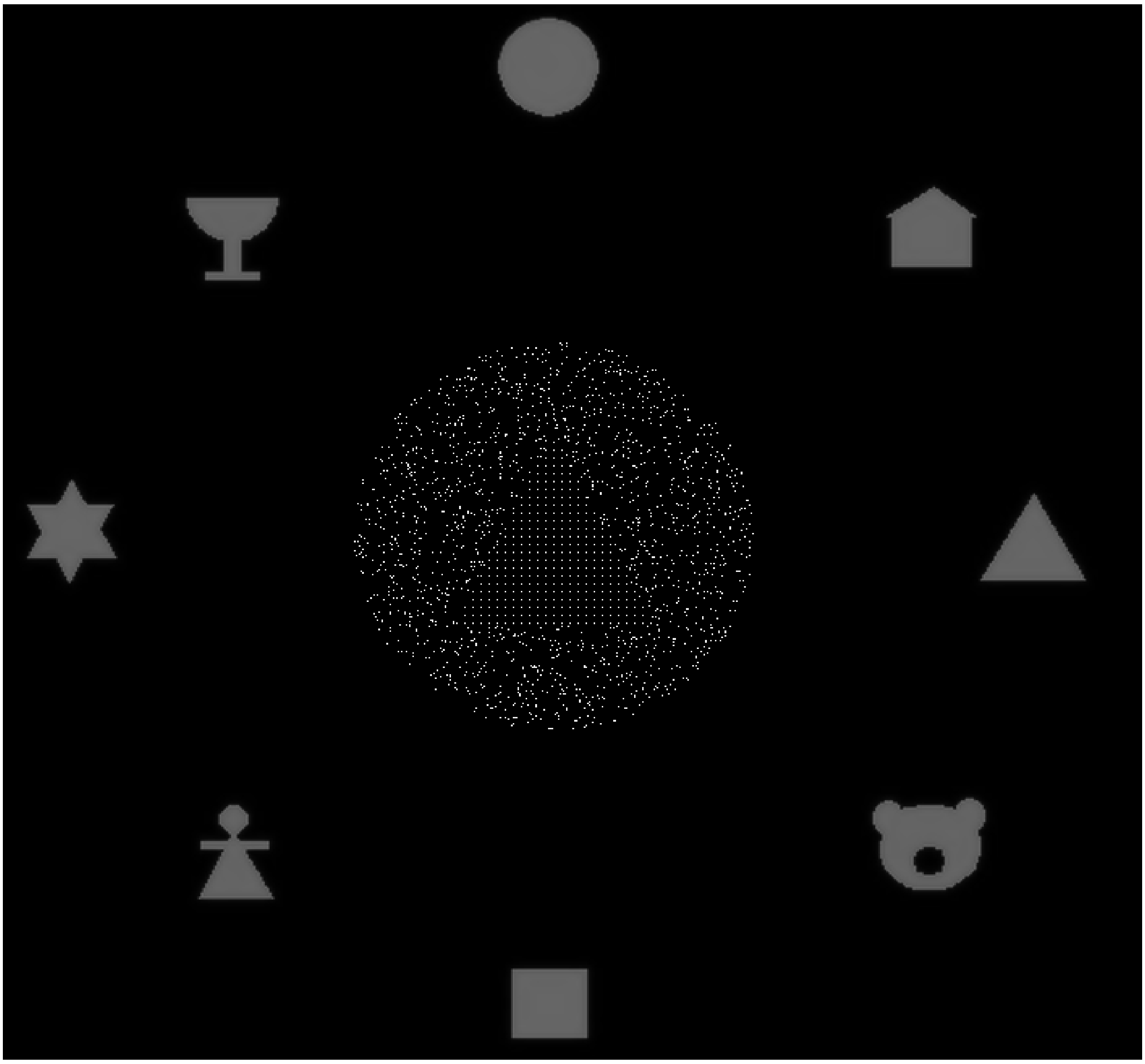

Figure 13 Form coherence test

Test of Visual-motor Integration (VMI)

The Beery VMI test (Beery, Buktenica & Beery, 1997) measures the extent to which individuals can integrate their visual and motor abilities in a paper and pencil task. It is a standardized measure commonly used to identify children who are having deficits with visual-motor integration and for clinical purposes.

Three subtests composed the test. In the VMI test, the subject is asked to copy geometric drawings onto a form using a pencil. Different levels of difficulty are presented and the drawings are showed in order of increasing difficulty. In the Visual Perception test the subject is asked to recognize a form within a set of similar shapes. In the Motor Coordination subtests, the subject's motor ability in drawing lines according to a specific map is evaluated. The accuracy in each subtest is computed by means of the sum of completed and corrected drawing items. Raw scores are transformed into Z scores according to normative data.

2.2.3 **Data Analysis:**

Two Generalized Linear Models (GzLMs) were conducted separately on the experimental data for Motion and Form coherence test. The Motion and Form accuracy *scores* (the number of correct answers divided by the total number of stimuli presented at each level of difficulty) were considered as the dependent variables. Binomial distribution (correct answer / wrong answer) with Logit as link function was used.

The probabilities of correct answer to each stimulus on the basis of the coherence levels were assessed using age (in years) as covariates.

As a second analysis, the accuracy scores were analyzed considering the different forms and the different directions. For this purpose, two GzLMs analysis were conducted. In the first the eight different forms were considered as within subject factor, in the second model the eight directions were considered the within subject factors. As in the previous models the age was used as covariate. Accordingly, binomial distribution (correct answer / wrong answer) with Logit as link function were used in the model.

The internal consistency was assessed by means of the Cronbach's alphas and non-parametric correlation analysis between coherence levels and total the motion and form coherence tests.

The convergent validity of the motion and form coherence test were evaluated on the basis of Spearman Rho correlation Coefficient considering the relationships between the accuracy in form coherence test in the 100% coherence level, the accuracy score in motion coherence test in the 100% coherence level, and the score in VMI test. The VMI test is a standardized test which allows to measure the visual perception and motor abilities. The VMI test doesn't uses background noise in order to evaluate the visual motor abilities, so the correlations were calculated with the 0% noise level of coherence. Finally, the reliability of Motion and Form coherence test was assessed by means of non-parametric correlation analysis (using Spearman's Rho coefficient) between the two administration of the tests.

Data were analyzed by using the Statistical Package for the Social Science (IBM-SPSS) version 20.

2.3 Results

2.3.1 General description of Motion Coherence test

A preliminary GzLM analysis showed, a significant gender effect ($Wald_5 = 6{,}568$; $p = .01$). In particular, male subjects showed a higher number of correct answer in comparison to females, as showed by odds ratio: 0,137 for males and 0,122 for females.

The analysis conducted by GzLM shows that the probability of responding correctly to the test changes significantly depending on the difficulty levels ($Wald_5 = 86{,}432$; $p < .01$).

The estimated odds ratio (OR) and the 95% confidence intervals (CI) (see table 1), showed that the coherence levels from 0 to 3 were significantly easier than the coherence level 4.

In particular, all of the difficulty levels had an Odds Ratio greater than 1, and this implies that the probability of correct response was higher in the levels 0, 1, 2 and 3 in comparison to the level 4. Furthermore, it could be noted that, the value of the odds ratio for the different levels, gradually decreases as the difficulty increases. So, the increment of the noise leads to a decrease in the probability of responding correctly to the stimulus (table 1).

Tab. 1. GzLM estimated parameters in the different levels of difficulty (Lev. 4 is set as reference).

Parameter	B	P	OR	Lower C.I.	Upper C.I.
Intercept	*-3.338*	*<0.01*	*.035*	*.030*	*.042*
Level 0	*1.269*	*<0.01*	*3.557*	*3.224*	*3.925*
Level 1	*1.106*	*<0.01*	*3.022*	*2.737*	*3.337*
Level 2	*.891*	*<0.01*	*2.438*	*2.213*	*2.686*
Level 3	*.444*	*<0.01*	*1.558*	*1.421*	*1.708*

The performance of the subjects expressed as mean of correct answers in different levels (and C.I.) is presented in figure 14. The graph shows the gradual decrement in the mean of correct answers as the difficulty increases. In particular, in the level 0 (100% of coherence), the mean of correct recognitions was around .84(M = .844; SE = .015), the score decrease gradually with the increase of difficulty up about .27 in the level four (M = .270, SE = .013).

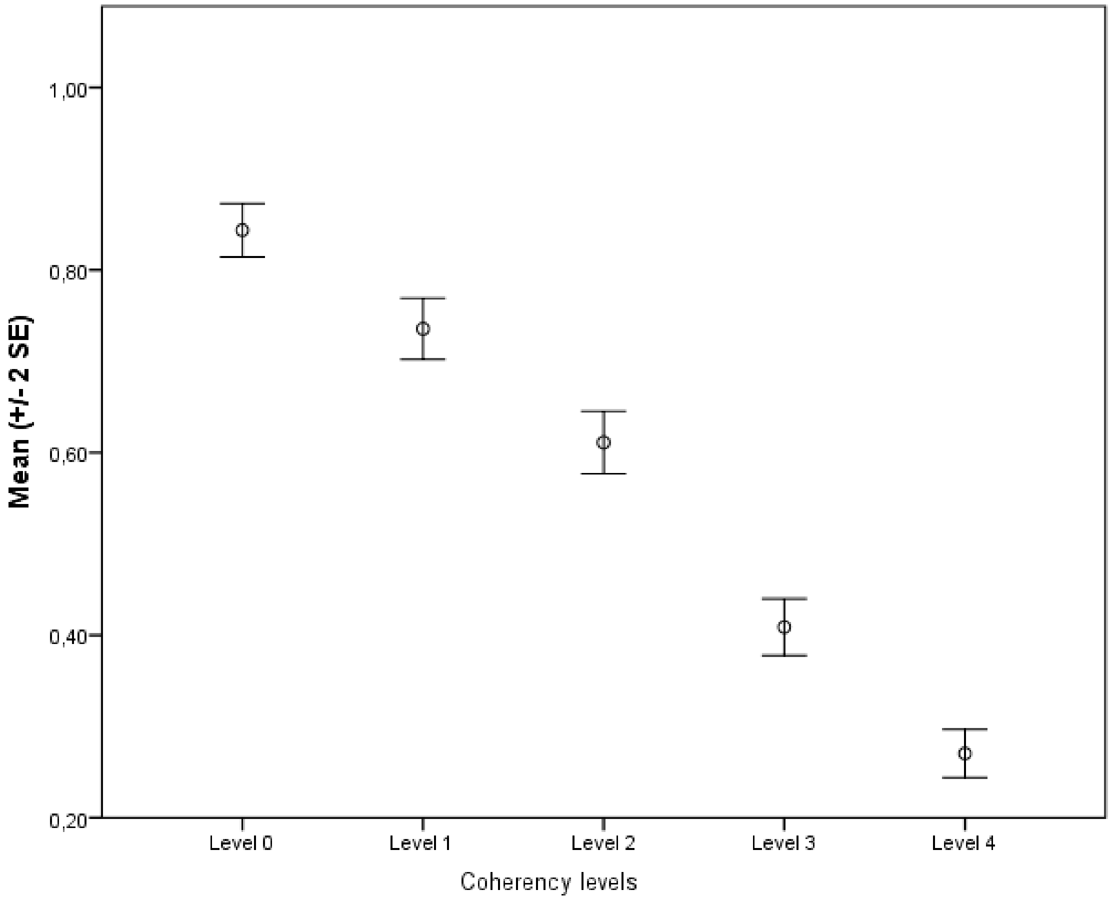

Figure 14 Percentages of correct answers in different levels of the Motion coherence test

The age, effect also resulted significant ($Wald_1 = 32.894$; $p <.01$), showing a positive effect on the number of correct response (OR = 1.10). Furthermore, the age by level interaction effect resulted significant ($Wald_4 = 24.50$; $p < .001$). The estimated OR showed that age significantly increased the probability of correct answer only in level 0 ($p <.001$; OR = 1.36).

From the analysis conducted by GzLM resulted that the different directions did not significantly change the probability to respond correctly to the task ($Wald_7 = 12.65$; $p=.10$).

The age effect was still significant ($Wald_1 = 30.27$; $p < .001$), while directions by age interaction effect did not result significant ($Wald_7 = 6.64$; $p = .47$).

2.3.2 General description of Form Coherence test

A preliminary analysis confirmed, that the gender effect was not significant neither for the main effect nor for interaction effect. Therefore, was not included in subsequent analyzes.

The analysis conducted by GzLM shows that the probability of responding correctly to the test changes significantly depending on the difficulty levels ($Wald_5 = 81{,}417$; $p < .01$).

The estimated odds ratio (OR) and the 95% confidence intervals (CI) (see table 2), showed that the coherence levels from 0 to 3 were significantly easier than the coherence level 4.

In particular, all of the difficulty levels had an Odds Ratio greater than 1, and this implies that the probability of correct response was higher in the levels 0, 1, 2 and 3 in comparison to the level 4. Furthermore, it could be noted that, the value of the odds ratio for the different levels, gradually decreases as the difficulty increases. So, the increase of the noise leads to a decrease in the probability of responding correctly to the stimulus (table 2).

Tab. 2. GzLM estimated parameters in the different levels of difficulty (Lev. 4 is set as reference).

Parameter	B	p	OR	Lower C.I.	Upper C.I.
Intercept	*-.683*	*<0.01*	*.505*	*.317*	*.804*
Level 0	*3.333*	*<0.01*	*28.009*	*7.597*	*103.261*
Level 1	*2.105*	*<0.01*	*8.211*	*4.864*	*13.861*
Level 2	*1.027*	*<0.01*	*2.794*	*1.804*	*4.327*
Level 3	*.527*	*0.02*	*1.694*	*1.069*	*2.684*

The performance of the subjects expressed as percentages of correct answers in different levels (and S.E.) is presented in figure 15. The graph shows the gradual decrease in the average percentage of correct answers as the difficulty increases. In particular, in level 0 (100% of coherence), the percentages of correct recognitions was around 100% (M = .982; SE = .004), the score decrease gradually with the increase of difficulty up about 40% in the level four (M = .45, SE = .015).

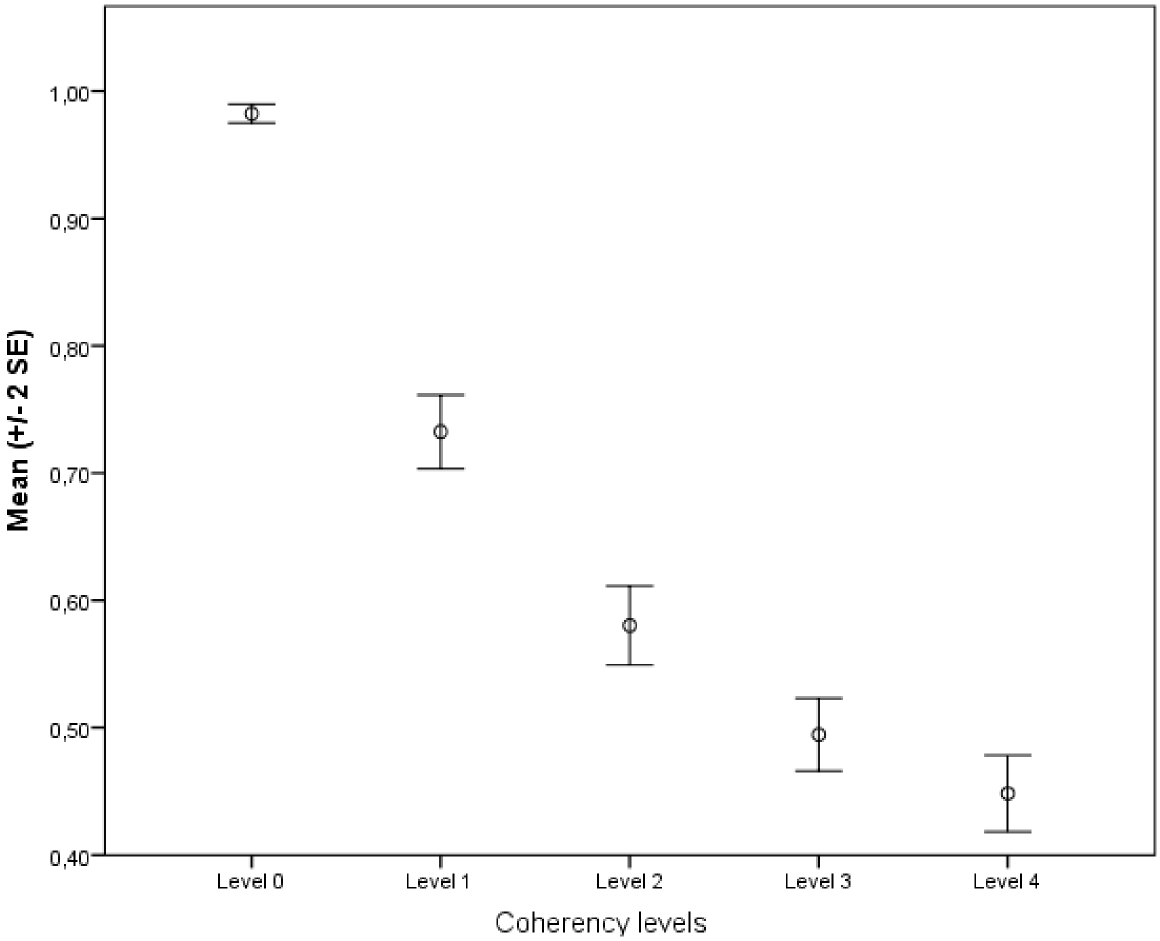

Figure 15 Percentages of correct answers in different levels of the Motion coherence test

The age effect was not significant ($Wald_1 = 2.496$; $p = .114$). The age by level interaction effect resulted however significant ($Wald_4 = 17,456$; $p = .002$). The estimated OR showed that age significantly increases the probability of correct answer only in level 0 and in level 4 (level 0: $p <.05$; OR = 1.189, Level 4: $p <. 01$; OR = 1.061).

From the analysis conducted by GzLM resulted that the type of shape significantly changed the probability to respond correctly to the task ($Wald_7 = 144.256$; $p <.01$).

The B parameters showed that, with the exception of the star, the other forms had a significantly different probability of correct response as compared to the triangle (see Table 3). The "triangle" form, resulted the hardest form to recognize, so was considered as reference category. The "cup" and "square" forms presented the highest OR values; indicating that these two forms increase the probability of recognition in higher way than the other.

The age effect was still not significant ($Wald_1$ = .016; p = .90), while form by age interaction effect resulted significant. The age effect was different for the different forms. It could be noted that for "star", "triangle" and "house" forms, the estimated number of correct answers increased with age. Conversely, in the "cup" and "square" forms, subject with the lowest age showed the greater number of correct estimated answers.

Tab. 3. GzLM estimated parameters in the different forms *(triangle is set as reference).*

Parameter	B	p	O.R.	Lower C.I.	Upper C.I.
Intercept	*-.898*	*<0.01*	*.407*	*.256*	*.649*
Cup	*3.690*	*<0.01*	*40.044*	*20.471*	*78.331*
Square	*2.787*	*<0.01*	*16.234*	*8.063*	*32.686*
Doll	*1.938*	*<0.01*	*6.945*	*3.573*	*13.500*
Butterfly	*1.762*	*<0.01*	*5.824*	*3.144*	*10.791*
Circle	*.998*	*<0.01*	*2.713*	*1.531*	*4.806*
House	*.644*	*.04*	*1.903*	*1.031*	*3.513*
Star	*.229*	*.49*	*1.258*	*.658*	*2.403*

2.3.3 Internal consistency

The Cronbach's alphas of the five coherence level showed a good internal consistency both for Motion test (Alpha=0.83) and for Form test (Alpha=0.78). Furthermore, the non-parametric correlations between each coherence level and the total showed a significant positive correlation for each level of the two tests (Table 4). Only the level 0 of the Form test didn't correlate with total score. This result depends of the saturation of this coherence level in Form test.

Tab. 4. Spearman's rho correlation coefficients between coherence levels and total of the Motion and Form coherence tests.

	Level 0	Level 1	Level 2	Level 3	Level 4
Motion test	.67**	.78**	.84**	.82**	.61**
Form test	.08	.74**	.86**	.79**	.77**

** Correlation is significant at the .01 level.

2.3.4 Convergent and divergent validity and reliability

The convergent validity between form and motion coherence scores with the VMI subscales was tested in a selected sample of 75 children. The 100% coherence level was considered for the analysis because in the VMI there is not the presence of the noise in the different stimuli used to calculate the accuracy score. The Spearman correlation analysis showed that the form coherence test at 100% coherence level (zero noise) showed a positive correlation with the score of VMI Visual perception subtest (Rho=.27; p=.03). None of the score at the motion coherence test was correlated with the different VMI subtests.

The divergent validity was investigated by means of Spearman correlation analysis among the motion and form coherence test scores. No significant correlation was found between the motion and form scores.

The reliability of motion and form coherence test was assessed by means of correlation analysis (using Spearman's Rho coefficient). The motion coherence test and form coherence test were administered to a specific sample of 51 subjects (20 female; age range 8-11 years; mean age 9.3) who performed the tasks in two separated sessions. The time interval between the two sessions was of half an hour. The analysis of correlation revealed a good reliability of the two tests (Motion coherence test reliability Rho = .67; $p < .001$; Form coherence test reliability Rho = .76; $p < .001$).

2.4 Conclusions

The results confirmed that the motion coherence test and form coherence test had good psychometric properties.

From the general description of the two tests it was possible to verify a general good acceptance of the tests by the population investigated, from five to twelve years of age. Indeed, in the global sample it was possible to verify a significant decrement of the accuracy by increasing the difficulty of the task. The percentage of correct answers in different coherence levels could be used to assess the ability to discriminate the signal from noise, and to investigate how the subject's performance varies with the variation of the signal/noise ratio.

Our results confirmed the gender effect in the motion perception that has been found in literature by several authors (Johnston et al., 2016a, 2016b; Melnick, Harrison, Park, Bennetto, & Tadin, 2013; Snowdon & Kavanagh, 2006). Males resulted more accurate in motion discrimination that females. Conversely, form discrimination didn't evidence this effect.

The analysis of the results of the Motion coherence test showed that the ability to discriminate the motion direction decreases as a function of the increment of noise, starting with 84% of correct detection with the 0% noise to the 27% of correct detection in the last level (that presented the 84% noise).

The general description of the Form coherence test revealed similar results. The analysis of the percentages of correct responses in the different coherence levels highlights how the probability of responding correctly to stimuli is reduced with the increment of noise (i.e. with the increase of the difficulty). Starting from the level 0, with a percentage of correct answers of 99%, and lasted in the level 4 with a mean percentage of correct answer of 45%.

The gradual decrement in the percentage of correct answers (higher than the chance level), showed that the Form and Motion coherence tests could be considered adequately calibrated for the reference population.

The analysis of the internal consistency evidenced a good Cronbach's Alfas indices and a good coherence level-total correlations for Motion and Form coherence tests.

Moreover, the indices criterion validity evidenced a convergent validity of the Form test with a test of vision-motor integration (VMI) and a divergent validity of the Motion and Form coherence test, confirming the different component of visual perception evaluated by the two tests. The two tests showed a good index of test-retest reliability. The measures of motion and form detection appeared stable in the two administrations of the tests.

Both the tests were useful to analyze how the age affect the perception performance. Older children are more capable to discriminate the motion and form information in comparison to younger children.

The analysis of the probability of correct response to the different forms evidenced significant differences. This result indicated that the proposed forms (representing both abstract and concrete shapes), presented different difficulties. Some of the stimuli resulted more easily recognizable than others. Probably the stimuli characterized by a higher number of details, are more recognizable also in higher noise levels, as compared to basic geometrical figures. Abstract figures probably do not present a high number of recognizable details in low coherence condition. This effect could also be linked to the fact that younger children are more used to everyday objects than abstract forms.

The use of Motion and Form coherence test allowed the evaluation of motion and form perception abilities in school age subjects. The use of these tests also allows to compare the performance of subjects of different ages.

The characteristics of the stimuli permit to overcome the limitations of the other tools available in the literature. The chance level is very low, 12.5%, as compared to other tests presented in literature. It's furthermore possible to test different noise levels in order to obtain an accurate assessment of the background noise effect. Furthermore, the tasks require an explicit identification of the form or the direction. Some of the previous instruments (Atkinson et al., 1997; Atkinson et al., 2006) do not require an explicit identification of the shape. In former tasks the subject is asked to indicate the position in which the stimulus is presented (right or left). The implicit identification of the shape could not correspond to the explicit identification. Furthermore, the association of both a form perception task and a position task may not properly be considered a ventral stream task.

From the results obtained in this study it will be possible to compute an appropriate index in order to analyze the response profile of the two test by using an appropriate psychophysical function.

Furthermore, it will be possible to investigate the developmental trajectories of these functionalities in a larger sample. It will also possible to obtain normative data that would allow to identify subjects who have performance below the norm for each age group. The results obtained in healthy population will be useful to evaluate abnormal visual functions in different developmental disorders.

3. Experiment 2 – The analysis of the response profile of Motion and Form coherence tests

Numerous studies in literature have dealt with the definition of the thresholds of behavioral psychophysiological tasks. In particular, for the definition of the thresholds of motion and form coherence perception, the staircase adaptive procedure seems to be one of the most common techniques (Ellemberg 2004; Armstrong & Maurer 2009; Hadad, Maurer & Lewis, 2011; Harvey, 1986). The goal of this procedure is to change the stimulus during the course of the trials to converge on that stimulus giving the desired performance level. The stimulus value is changed by a fixed value (i.e. the step size), when the subject fail to recognize the stimulus, the direction of steps is changed. After a given number of inversion the task stops. The final estimate is obtained by averaging the reversal point (Treutwein, 1995). Anyway, this technique is not exempt from some criticism. The number of trials that could be necessary in order to determine the threshold limit could be in fact very high; this can be visually fatiguing the subject, making it difficulty suitable for children. A different approach could be represented by the method of constant stimuli, similar to the one used by Lewis and colleagues (2002). A number of suitably located points in the physical stimulus domain are chosen. These stimuli are repeatedly presented to the subject. The cumulative responses could be considered as the output of the test, i.e. the number or the percentage of correct response or could be used to estimate points on a psychometric function. Fitting psychometric function to experimental data is a common technique used in literature (see e.g. Parrish, 2005; Lewis, 2002). This process consists of finding an appropriate function that allows to fit the experimental data. The use of an appropriate function allows furthermore to define the stimulus threshold, express as the level of the stimulus that leads to a preselected level of correct answer (e.g. 75%).

The analysis of literature shows that the different methods and outcomes that are commonly used in literature in order to define the thresholds or the responses profile of a behavioral psychophysiological task are heterogeneous and not exempt of criticism. The aim of this experiment is to present and to analyze the response profiles of two tasks designed to assess the Motion coherence and the Form coherence perception in children and adults. The use of an appropriate function to fit the data will allows to compare the results deriving from tests that uses different noise levels, i.e. the preschool and the school versions of the two tests.

3.1 **Folded normal distributions and Half normal distributions**

The normal distribution describes a family of continuous probability distributions, having the same general shape, and differing in their location (i.e. the mean or average; μ) and scale parameters (i.e. the standard deviation; σ). The graph of its probability density function is a symmetric and bell-shaped curve. The development of the general theories of the normal distributions began with the work of de Moivre (1733, 1738) in his studies of approximations to certain binomial distributions for large positive integer n > 0. Further developments continued with the contributions of numerous authors throughout the years. The normal distribution is perhaps the most important in probability and is used to model a huge number of random phenomena throughout the different branches of science. For this reason, the normal distribution has been extensively studied, both from theoretical and applicative point of view (Ahsanullah, Kibria & Shakil, 2014).

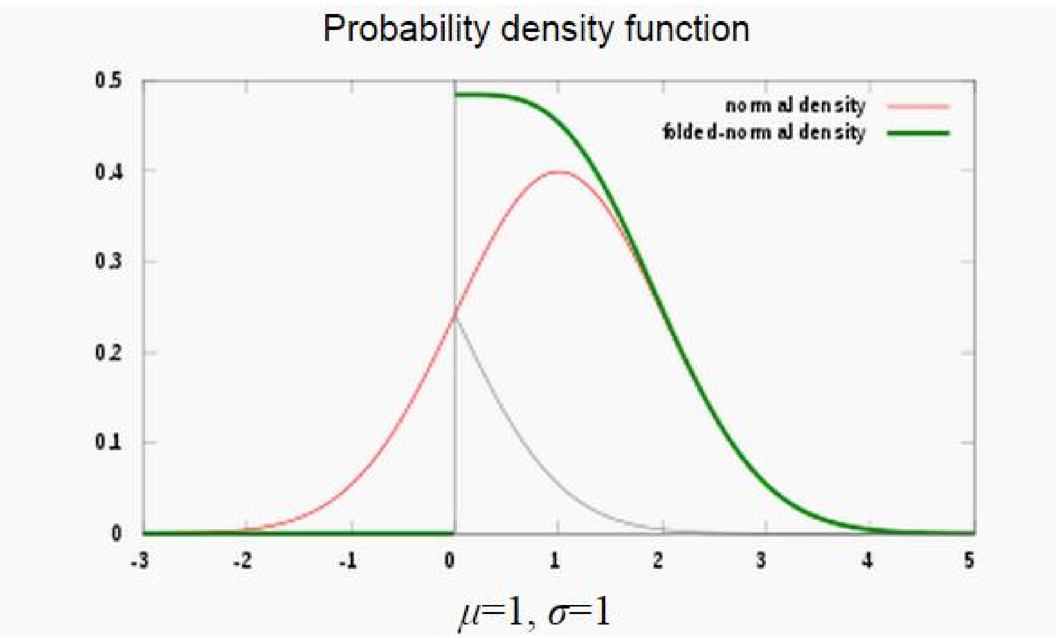

Figure 16 – Probability density functions of the Normal and the Folded-normal distributions

The folded normal distribution is the distribution of the absolute value of a random variable with a normal distribution. Probability measure of the normal distribution on $(-\infty,0]$ is folded over to $[0,\infty)$ (Fig. 16)

Half-normal distribution consists in a special case of folded normal distribution in which $\mu = 0$, and the scale parameter (σ) is 1. Statistical methods dealing with the properties and applications of the half-normal distribution have been extensively used by many researchers in diverse areas of applications, particularly when the data are truncated from below (that is, left truncated,) or truncated from above (that is, right truncated).

A continuous random variable X is said to have a (general) half-normal distribution, with parameters μ (location) and σ (scale), that is, $X|\mu, \sigma \rightarrow HN(\mu, \sigma)$, if its pdf (probability density function) fX (x) and cdf (cumulative density function) FX (x) = P(X ∈ x) are, respectively, given by

$$f_X(x|\mu,\ \sigma) = \sqrt{\frac{2}{\pi}}\frac{1}{\sigma}e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}, \quad F_X(x) = erf\left(\frac{x-\mu}{\sqrt{2}\sigma}\right)$$

where $x \geq \mu$, $-\infty < \mu < \infty$, $\sigma > 0$, and erf denotes error function.

$X = \mu + \sigma\,|Z|$, where $Z \rightarrow N(0, 1)$ has a standard normal distribution. On the other hand, the random variable $X = \mu - \sigma\,|Z|$ follows a negative (general) half- normal distribution. In particular, if $X \rightarrow N(0, \sigma^2)$, then it is could be see that the absolute value $|X|$ follows a half normal distribution, where μ is the location parameter and σ is the scale parameter. If $x \leq \mu$, then the pdf is undefined (Fig 17).

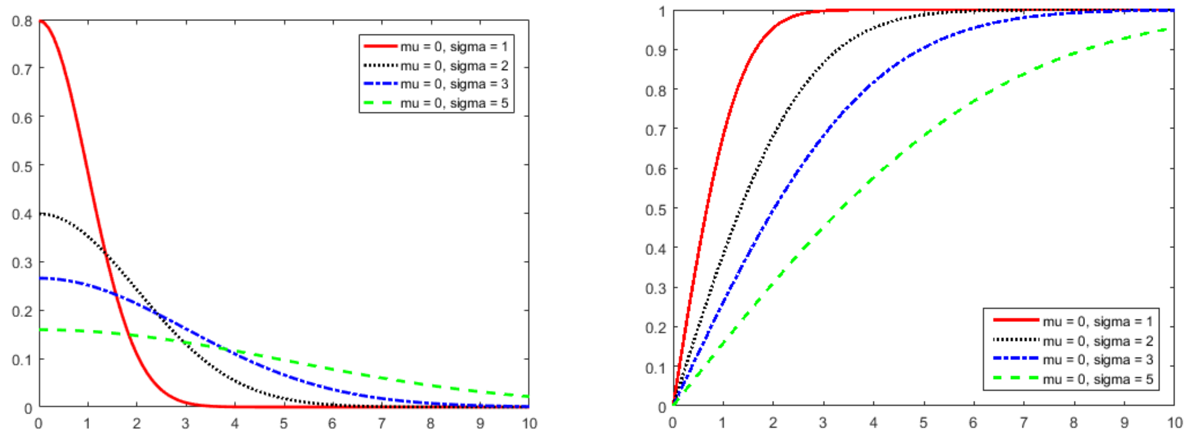

Fig. 17 - Half-normal distribution: probability density function (left) and cumulative density function (right)

As discussed by Halberda and colleagues (2008), the use of a psychophysical model as Weber function, error function or half-normal function, could present several advantages as compared to a sigmoid model. Authors suggested that even if the sigmoid model showed more accurate fit than the psychophysics model, the greater number of free parameters determines a reduction of parsimony. Furthermore, in particular for older children and adults the fit of the psychophysics model resulted adequate.

Considering the its characteristics, the half normal distribution seems to be one of the most useful function to fit the response profile of the motion coherence and the form coherence tests.

3.2 **Aim**

The aim of this study is to evaluate the applicability of a half normal psychophysical function to the accuracy profiles obtained by Motion and Form coherence test. The response profile of the two tasks will be fitted with an appropriate psychophysical function, that estimates the discrimination performance (i.e. the number of correct responses) on the basis of the coherence level of a stimulus. The efficiency of this estimation will be evaluated using R-squared adaptation coefficient and comparing the results of the response profiles with the estimated curves. The adaptation coefficient of the half-normal model will be compared to a linear model. This investigation will allow to clarify the characteristics of the response profile of the two presented tasks.

3.3 **Methods**

3.3.1 **Participants:**

The sample was composed by 48 adults from 20 to 34 years old (32F 16M, mean age: 23.6 SD: 3.0). The two tests were administered in a single session. The Form coherence test with 3db of coherence decrement, and Motion coherence test with 2db of coherence decrement.

3.3.2 **Measures and procedures**

The tests were administered individually to the participants in one sessions of about 15-20 minutes. The presentation order was randomized. A psychologist was present for the whole experiment. Subjects weren't affected by neuropsychological problems or sensory impairments.

Motion coherence test:

Motion perception was evaluated with the Motion Coherence Test (Benassi, Rydberg, Belli, & Bolzani, 2003; Menghini et al., 2010), a computerized behavioral test designed to assess dorsal pathway functionality. On a black background (0.2 cd/m2), 150 high luminance dots (luminance 51.0 cd/m2) could move coherently at a constant speed (6.1°/s) in one of the eight directions of the space (4 cardinal and 4 oblique). Dots are displayed on a computer screen at a distance of 130cm from the participants and subtended a visual angle of 5°. To avoid the possibility of tracking, each dot has a limited lifetime of 4 animation frames (duration = 200 ms). The task consisted of 5 levels of difficulty, each one compose by 8 trials. Coherent motion percentage is defined as the number of dots in coherent motion on the total of dots. The non-coherent dots moved randomly between frames in a Brownian manner. Practice trials are completed to familiarize participants with fixation, stimuli presentation and responding. Starting from a condition of 100% coherence (all the dots moved coherently in one direction), at each step the noise (Brownian motion dots) increases of 2db (each level has a decrement of 37% of coherent dots as compared to former). Therefore, the difficulty increases in each level. Participants are asked to indicate the direction of the perceived motion by choosing between the 8 possible directions. The chance level is thus 12.5%, a lower level as compared with other instruments presented in literature. The subject's motion perception ability is calculated as the mean of the correct answer for each level. In addition, for each subject it will be possible to evaluate the percentage or the mean of the correct answer for each direction. This kind of test is supposed to elicit the magnocellular system - dorsal pathway because it's based on high temporal frequency stimuli and the subject is asked to make a *where task*. The motion perception is allowed by the coherent motion stimuli that move as a group, for that reason the stimuli is considered global motion task. The motion is based on luminance level; thus it could be considered as a first order motion stimuli. This aspect could cope with the criticism reported by Skottun and Skoyles (2011) regarding the use of contrast sensitivity tasks in order to elicit magnocellular functionality.

Form Coherence Test:

Form perception was evaluated with the Form Coherence Test. This computerized behavioral test is a new computer based tool designed to assess ventral pathway functionality. On a black background (0.2 cd/m2), 1962 static high luminance dots (luminance 51.0 cd/m2) are displayed at a distance of 130cm from the participants and subtended a visual angle of 5°. A part of the dots produce, with a coherent spatial continuity, one of the 8 possible forms: circle, square, triangle, star, house, doll, glass. The others dots, representing the background noise, are disposed randomly. Practice trials are completed to familiarize participants with fixation, stimuli presentation and responding. The task consisted of 5 levels of difficulty each one composed by 8 trials. The coherence is defined as the number of spatially aligned dots on the total of dots presented in the frame. The noise is represented by dots that are randomly disposed in the frame. Starting from a condition of 100% coherence, at each step the noise increases of 3db (each level has a decrement of 50% of coherent dots compared to former). Therefore, the difficulty increases in each level. Participants are asked to indicate the correct form, choosing between the 8 possible forms. The chance level is thus 12.5%, a lower level as compared with other instruments presented in literature. The subject's form perception ability is calculated as the mean of the correct answer for each level. In addition for each subject it will be possible to evaluate the percentage or the mean of the correct answer for each form. This kind of test is supposed to elicit the parvocellular system - ventral pathway because it's based on high spatial frequency stimuli and the subject is asked to make a *what task*. The use of luminance defined stimuli could cope with the criticism reported by Skottun and Skoyles (2011) regarding the use of contrast sensitivity tasks in order to elicit parvocellular functionality.

3.3.3 **Data Analysis:**

In order to determine Motion and Form coherence perception thresholds, half normal psychometric functions were estimated. These functions allowed to relate the coherence levels of the stimuli with the discrimination performance (i.e. the percent of correct responses). The use of appropriate psychometric functions allows to statistically define the thresholds of the Motion and Form coherence perception abilities, defined as the level of coherence of the stimulus that can be discriminated in 75% of the presentations. The model that was used is based on the cumulative half normal distribution of probability, defined by the equation:

$$accuracy = erf\left(\frac{coherence}{W\sqrt{2}}\right) \times .875 + .125.$$

The parameter W represents an estimation of the standard deviation of the distribution. The value of 0.125 indicates the accuracy when the coherence is 0%, that is equal to the chance level of the two tests. A small W corresponds to a steeper curve, while a large W produced a flat curve (Fig. 18). Subsequently, a small W parameter represent a good subject/age group ability in form or motion recognition. The parameter was estimated with an iterative method for nonlinear optimization, the sequential quadratic programming. The initial value for the parameter was specified as 0.5. The model was determined using sum of squared residuals as a loss function. Finally, the goodness of fit between the model and the data was assessed by using the coefficient of determination (R-squared) as an indicator of the proportion of the variance explained by the nonlinear regression model. Furthermore, by using the psychometric function it's also possible to estimate the level of coherence in which the stimulus could can be discriminated in 75% of the presentations. Furthermore, in order to compare the obtained solution with a linear model, two linear regression analysis were conducted for Motion and Form tests, using the coherence as predictor and the accuracy scores as dependent variables.

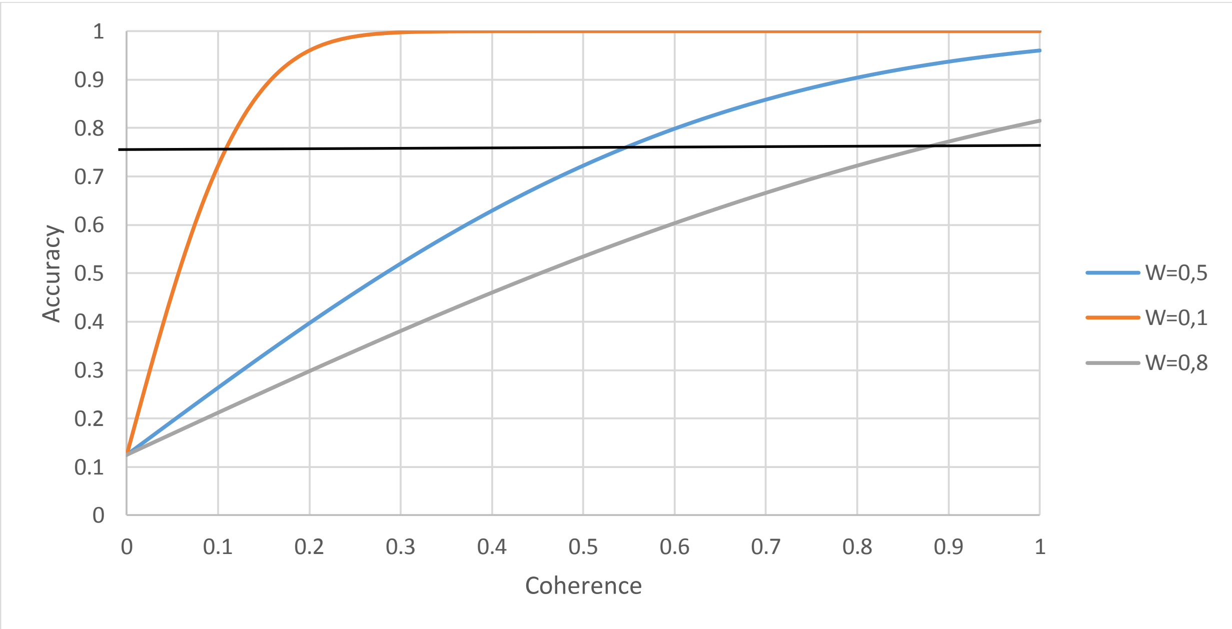

Figure 18 Half-normal functions with different W parameters

3.4 **Results:**

Table 5 reported the mean (and SD) of the correct responses for the five difficulties levels and totals of the Motion coherence and the Form coherence tests. Table 5 showed also the result of the nonlinear regression analysis conducted in order to fit the behavioral data with a half-normal cumulative function. The estimated scores appear in particular for the Motion test to be similar to the means of the difficulty levels (Fig. 18, 19 and 20). Regarding the estimation of the parameters W it could be noticed that subjects showed at Motion and Form similar levels of W. W could be interpreted as an estimation of the standard deviation of the half-normal cumulative distribution curve. Small values of W produce a steeper curve, that indicates a good discrimination ability. The estimated function presented a fit index R-squared of 0.39 for the Motion test and of 0.27 for the Form test.

By using the psychometric function it's also possible to estimate the level of coherence in which the stimulus could can be discriminated in 75% of the presentations. For Motion coherence test, the function estimated that adult subjects obtained the 75% of correct discrimination at a level of coherence of 0.33. Subjects obtain that percentage of correct discrimination at a level of coherence of 0.27.

The linear regression analysis conducted on the same sample showed, for Motion coherence test a significant model ($F_{1,239}$=150.5 p<0.01) with a R-squared of 0.39 (B=0.50, constant=0.52). The regression analysis conducted on Form coherence test also showed a significant model ($F_{1,234}$=303.4 p<0.01) with a R-squared of 0.56 (B=0.52, constant=0.50).

Table 5 Mean (and SD) of the correct responses for the five difficulties levels and totals of the Motion coherence and the Form coherence tests. Parameters estimation, fit index and estimated scores of nonlinear regressions analysis.

Motion			
Coherence level	**Mean Response**	**SD**	**Estimate Score**
100%	.98	.07	1.00
63.1%	.89	.14	.96
39.8%	.77	.22	.82
25.1%	.66	.22	.63
15.8%	.53	.22	.46
Total	.79	.12	

Parameters estimation and fit index:
W= 0.31 SE= 0.01   95% CI= 0.29 – 0.34
R-sq=0.39
Coherence 75% of correct responses= 0.33

Form

Coherence level	Mean Response	SD	Estimate Score
100%	.99	.02	1.00
50.1%	.82	.16	.96
25.1%	.62	.16	.72
12.6%	.56	.17	.46
6.3%	.51	.20	.30
Total	.73	.08	

Parameters estimation and fit index:
W= 0,25 SE=0.01 95% CI= 0.23 – 0.28
R-sq= 0.28
Coherence 75% of correct responses= 0.27

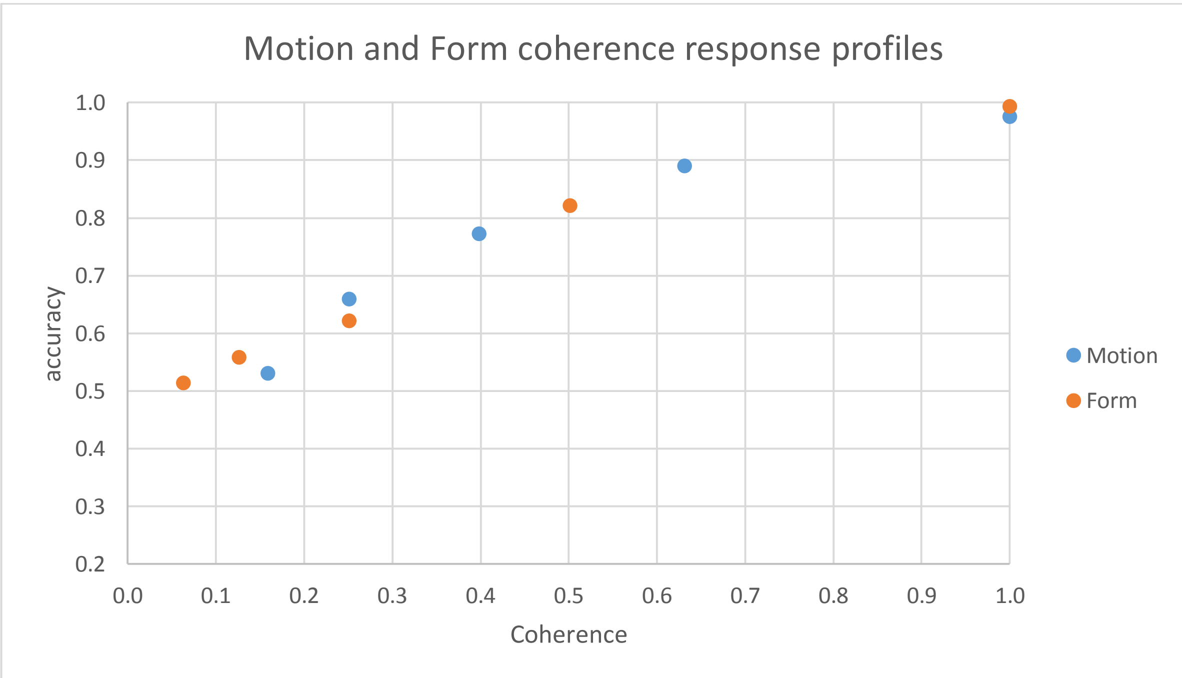

Fig. 18 Comparison between Motion and Form coherence response profiles

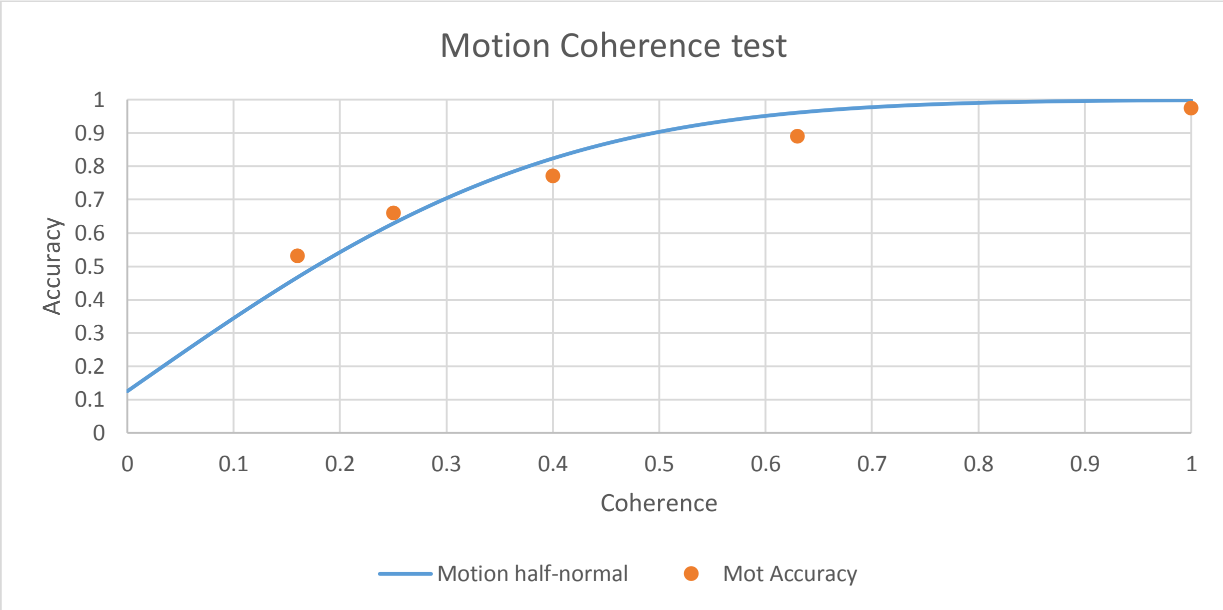

Fig. 19 – Motion response profiles and predicted values of the nonlinear regression analysis

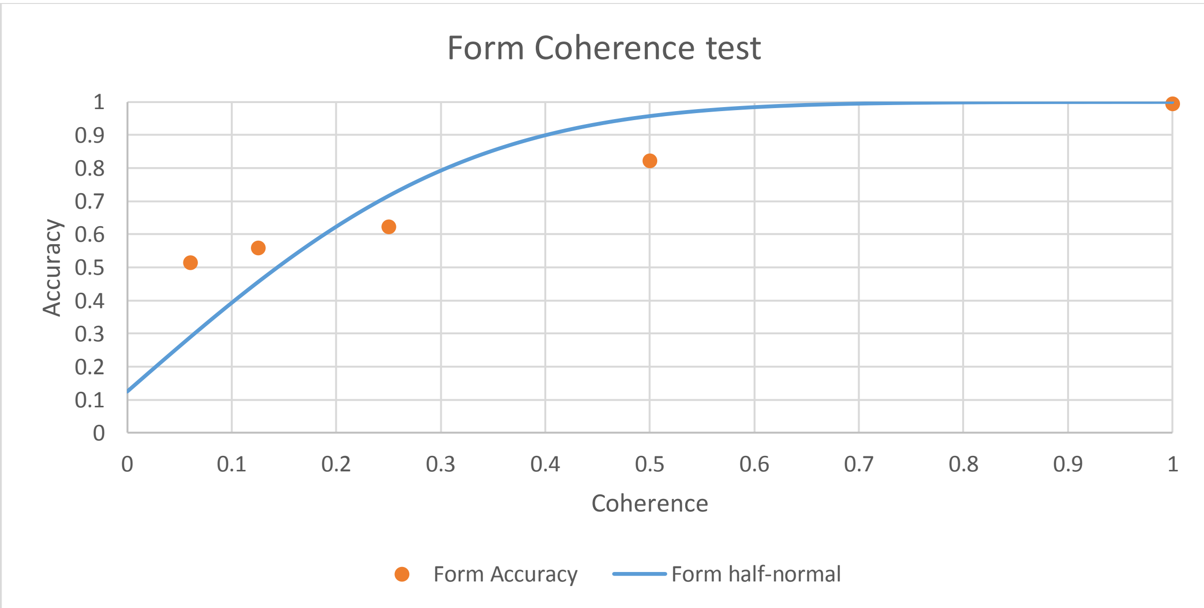

Fig. 20 – Form response profiles and predicted values of the nonlinear regression analysis

3.5 **Conclusions**

The fitting function selected for the evaluation of motion and form perception accuracy obtained, in particular for Motion coherence test, a quite good index of goodness of fit, suggesting the adequateness of half-normal cumulative function to represent motion coherence perception data. Interestingly, in the harder levels (i.e. the levels with low coherence), Form perception ability seems to remain stable as the level of coherence decreases. This result cannot be related to the floor effect determined by chance level. In fact, in our instrument, chance level is 12.5%, while the percentages of correct form detection in the low coherence levels is about 50%. We suppose that this phenomenon could be determined by the characteristics of the stimuli; in fact some form could remain easily detectable also in low coherence condition.

The linear regression analysis, conducted to analyse the experimental data showed for the Motion test the same adaptation index (R-squared) of the non-linear regression. However, it's interesting to note that the estimated constant did not represent a good approximation of the chance level of the tests. So, the linear model did not seem to be an effective model of the motion perception functionality. Furthermore, the use of only one free parameter (W) in the nonlinear model determines high parsimony.

This encouraging result point out the strengths of the Motion and Form coherence tests in a sample of adults. Further studies will test the same abilities in a sample of child and adolescents, in order to define the developmental trajectories and the characteristics of the response profiles in children of different ages. The use of the psychophysical function will allow to summarize the profiles information using only a parameter (W) instead of 5, and to compare the performance of test with different levels of coherence. It will also be possible to determine the perceptive thresholds, in a less time spending methodology as compared to staircase procedure.

4. Experiment 3 – Developmental trajectories and normative profiles of Motion and Form perception ability

The development of human visual system has been investigated so far from different kind of studies. Some of them demonstrated that the development of the two streams is different at different ages (Braddick & Atkinson, 2011). Even if the ability to discriminate local direction develops later than the orientation sensitivity, infants seem to be more capable to individuate global motion than static stimulus (Braddick & Atkinson, 2011). Braddick and Atkinson (2007) found that eight-weeks infants show a significant preference to motion coherence with little changes over the following ten weeks. In contrast, the response to global form in that period is initially at chance and it shows an increasing preference over the same period. The developmental trajectories of global motion and global form perception appear to change again in older children: however, the age at which them reaches adult levels remains unclear (Narasimhan & Giaschi, 2012). Psychophysical testing using motion coherence threshold measures has showed various maturation curves for global motion perception. Parrish and colleagues (Parrish et al., 2005) tested children from 3 to 12 years old and adults with random dots kinematograms stimuli. Dots moved at 1.2 deg/s in a coherent direction: upward or downward. Authors did not find any significant improvement with age in motion detection thresholds, suggesting that global motion perception could mature before 3 years of age. Other researchers found that global motion sensitivity mature by 6 years of age (Ellemberg et al., 2002) or develops even later, not before the age of 11 and shows a greater variability (Gunn et al., 2002; Armstrong, Maurer, & Lewis, 2009). In particular, Armstrong, Maurer and Lewis (2009), using stimuli constituted by sinusoidal grating vertical drifted to the left or to the right, found that children at 10 years of age still perform significantly poorer than adults in motion detection. Authors suggested that children's immature thresholds for motion cannot be only attributed to poor sensitivity to the form carrying the motion signal. Specifically, children reached adult-like thresholds for both first- and second-order form before motion. Furthermore, Hadad and colleagues (2011) tested participants from 6 to 14 years old with a monocular presentation of random-dot kinematograms stimuli (upward vs. downward) moving at a velocity of 4 deg/s and 18 deg/s. Authors found that children did not reach adult like motion detection thresholds before the 12-14 years of age for both the speed condition (slow and fast dots). These results suggest that the ability to integrate local motions into a global pattern of motion is related to a group of visual functions with protracted developmental sequences. However, the monocular presentation of the stimuli could influence the particularly late development found by the authors.

Psychophysical testing using motion coherence threshold measures has shown various maturation curves. This great variability seems not be accounted only to the ability to separate signal dots from noise (Hadad et al., 2015). Narasimhan and Giaschi (2012) evidenced that the stimulus parameters, particularly dot speed and dot density vary consistently across the different studies. These aspects could explain, at least partially, the discrepancies of the results. Specifically, while adult coherence thresholds appear to be relatively unaffected by stimulus parameters, both speed and density have a significant effect on thresholds for children. At age 6, global motion is less mature for slow than fast speeds and particularly for sparse relative to higher densities.

A few number of studies have dealt with the developmental trajectories of form perception, finding heterogeneous results. A study conducted by Parrish, Giaschi, Boden, and Dougherty (2005) found that accuracy on a texture-defined form task continues to improve at least until 12 years of age. Armstrong and colleagues (Armstrong, Maurer, & Lewis, 2009), testing children from 3 to 10 years old with horizontal or vertical stationary sinusoidal gratings, found that first-order form did not reach adult-like thresholds until 10 years of age, while corresponding second-order form thresholds is still mature at 5 years of age. Another study, conducted by Gunn and colleagues (2002), used a stimulus composed by a static array of randomly orientated short line segments containing concentric circles to test children from 4 to 11 years old. Results revealed that that form coherence thresholds were not significantly different from adult levels in the 6- to 7-year-old group and above.

The comparison between the different rates of development of motion and form recognition abilities seems not cleared yet. The study conducted by Parrish and colleagues (2005) evidenced that figure-ground segregation and shape identification, that are considered ventral visual-stream functions, were still maturing in school age children. Conversely, motion perception (a dorsal-stream function), was already developed at that age (Parrish et al., 2005). Furthermore, neuroimaging studies seems to support protracted ventral development, showing that while ventral abilities improve over the adolescence, dorsal abilities complete their development in the adolescent period (Grill-Spector, Golarai, & Gabrieli, 2008). Conversely, other findings showed a later dorsal than ventral visual-stream development. Gunn and colleagues (2002) indicated that the age profile of improvement of the two functions in average performance was essentially parallel. However, on motion perception there are indications of more poorly performing outliers in the youngest group, and a slight lag in development compared to form coherence ability. Furthermore, other studies show an earlier white-matter maturation of ventral-stream structures, which mature as 7 years of age, as compared to dorsal-stream structures, which continue to mature until early adulthood (Lebel et al., 2008).

4.1 **Normative profiles**

The use of the general population data in order to define the normative profiles of the motion and form discrimination abilities lead to the problem of which parameter could be considered the most appropriate. For clinical proposes, the transformation of the parameter in z-scores is one of the most common methodology. Z-scores results in fact easily understandable and very informative for clinicians of different formation. However, several methodological problems arise when the distribution of the considered parameter appear to be pretty different from the Gaussian distribution (see Fig. 21). In fact, in this case, the obtained results tend to be significantly unreliable, in particular when the skewness of the distribution in considerably marked. This methodological problem was widely discussed in literature, in particular regarding the response time (Van Zandt & Townsend, 2014). Even if the transformation of the response time in z-score is a common praxis, its distribution appears to be often pretty different form the normal. In particular, response time distribution often appears to be asymmetrical (left skewed) and more similar to the ex-Gaussian distribution (Wagenmakers e Brown, 2007) than to Gaussian. A different approach that has been proposed by several authors (see Losito, Tressoldi & Cornoldi, 2014) in order to cope with non-normal distributions, is represented by non-parametric statistics and, in particular by non-parametric percentiles. Non-parametric percentiles are commonly used in medical and pediatric practices, their main strength is that is not necessary to postulate any assumptions about the distribution of the scores. In fact the calculation of percentiles is done on the "real" sample and not on the theoretical distribution of scores. In the case of normally distributed (Gaussian) scores, the correspondence between z-scores and percentiles follows a fixed rule of conversion: -1 SD in z-scores correspond to the 15.9 percentiles, while -2 SD to the 2.3 percentiles (Fig. 21). The most the distribution of the scores differ from the Gaussian, the most the correspondence between z-score and percentiles become unreliable.

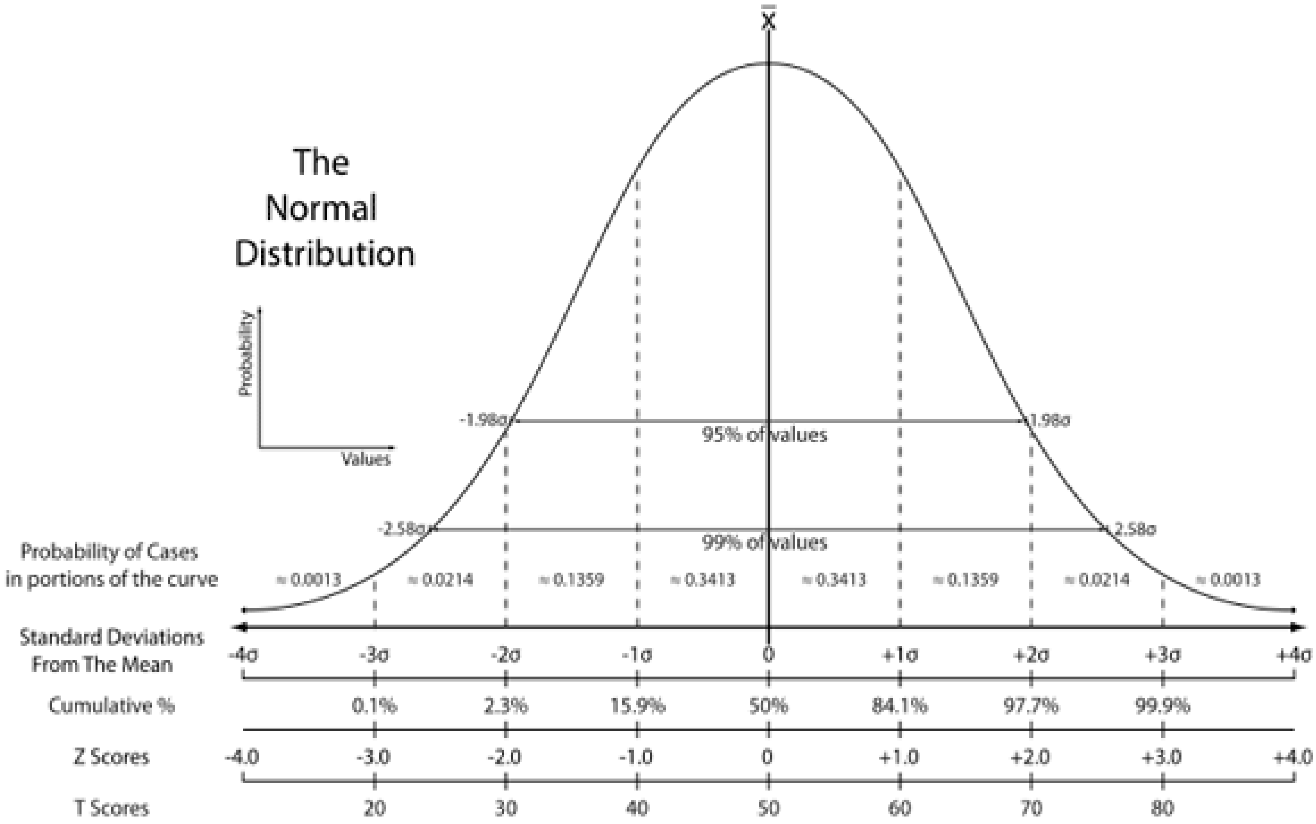

Figure 21 – Comparison between Z-scores and percentiles in the Normal distribution

4.2 **Aim**

The main purpose of this research is to analyze the developmental trajectories of dorsal and ventral streams in typically developing children. In order to compare the performance of tests with different levels of coherence (preschool and school version of the tests), an appropriate psychophysical function has been applied. As second objective, the study aims to determine the normative profiles for Motion and Form coherence test for each class of ages. It will be conducted a comparison between the normative limit calculated ad standard deviation from the mean (i.e. transformation in z-scores) and the one calculated by nonparametric percentiles.

4.3 **Methods**

4.3.1 **Participants:**

The sample was composed by 414 children between 4 and 13 years (210 males; age mean=8.35 SD=2.84) and 48 adults between 20 and 34 years (16 males; age mean=23.97 SD=2.95) collected in the preschools, primary and secondary schools of Forlì and Cesena during screening projects and in the Department of Psychology, University of Bologna. Children and adults were divided in age groups (see table 6). Children aged 4 and 5 years (preschool children) performed the 1 db. version of the Motion test and the 1.5 db. version of the Form test. Older children and adults performed the 2 db. version of the Motion test and the 3 db. version of the Form test.

Table 6 – Descriptive statistics of different class of ages

Age group	N	males	Mean Age	SD
4.0 – 4.12	52	26	4.46	0.32
5.0 – 5.12	49	22	5.36	0.27
6.0 – 6.12	25	10	6.58	0.21
7.0 – 7.12	35	19	7.44	0.27
8.0 – 8.12	41	23	8.40	0.27
9.9 – 9.12	43	25	9.47	0.25
10.0 -10.12	60	32	10.44	0.25
11.0 – 11.12	44	22	11.37	0.30
12.0 – 12.12	37	21	12.37	0.22
13.0 – 13.12	28	9	13.32	0.26
Adults	48	16	23.97	2.95

4.3.2 Measures and procedures

The tests were administered individually to the participants in two sessions of about 15-30 minutes. The presentation order was randomized. A psychologist was present for the whole experiment. Furthermore, in order to exclude cognitive delays and visual impairments, visual function and general intelligence were also assessed for each subject.

Motion coherence test:

Motion perception was evaluated with the Motion Coherence Test (Benassi, Rydberg, Belli, & Bolzani, 2003; Menghini et al., 2010), a computerized behavioral test designed to assess dorsal pathway functionality. On a black background (0.2 cd/m2), 150 high luminance dots (luminance 51.0 cd/m2) could move coherently at a constant speed (6.1°/s) in one of the eight directions of the space (4 cardinal and 4 oblique). Dots are displayed on a computer screen at a distance of 130cm from the participants and subtended a visual angle of 5°. To avoid the possibility of tracking, each dot has a limited lifetime of 4 animation frames (duration = 200 ms). The task consisted of 5 levels of difficulty, each one compose by 8 trials. Coherent motion percentage is defined as the number of dots in coherent motion on the total of dots. The non-coherent dots moved randomly between frames in a Brownian manner. Practice trials are completed to familiarize participants with fixation, stimuli presentation and responding. Starting from a condition of 100% coherence (all the dots moved coherently in one direction), at each step the noise (Brownian motion dots) increases of 2db (each level has a decrement of 37% of coherent dots as compared to former). Preschool children performed the 1 db. version of the test (each level has a decrement of 21% of coherent dots compared to former). Therefore, the difficulty increases in each level. Participants are asked to indicate the direction of the perceived motion by choosing between the 8 possible directions. The chance level is thus 12.5%, a lower level as compared with other instruments presented in literature. The subject’s motion perception ability is calculated as the mean of the correct answer for each level. In addition, for each subject it will be possible to evaluate the percentage or the mean of the correct answer for each direction.

This kind of test is supposed to elicit the magnocellular system - dorsal pathway because it's based on high temporal frequency stimuli and the subject is asked to make a *where task*. The motion perception is allowed by the coherent motion stimuli that move as a group, for that reason the stimuli is considered global motion task. The motion is based on the level of luminance; thus it could be considered as a first order motion stimuli. This aspect could cope with the criticism reported by Skottun and Skoyles (2011) regarding the use of contrast sensitivity tasks in order to elicit magnocellular functionality.

Form Coherence Test:

Form perception was evaluated with the Form Coherence Test. This computerized behavioral test is a new computer based tool designed to assess ventral pathway functionality. On a black background (0.2 cd/m2), 1962 static high luminance dots (luminance 51.0 cd/m2) are displayed at a distance of 130cm from the participants and subtended a visual angle of 5°. A part of the dots produce, with a coherent spatial continuity, one of the 8 possible forms: circle, square, triangle, star, house, doll, glass. The others dots, representing the background noise, are disposed randomly. Practice trials are completed to familiarize participants with fixation, stimuli presentation and responding. The task consisted of 5 levels of difficulty each one composed by 8 trials. The coherence is defined as the number of spatially aligned dots on the total of dots presented in the frame. The noise is represented by dots that are randomly disposed in the frame. Starting from a condition of 100% coherence, at each step the noise increases of 3db (each level has a decrement of 50% of coherent dots compared to former). Preschool children performed the 1.5 db. version of the test (each level has a decrement of 29% of coherent dots compared to former). Therefore, the difficulty increases in each level. Participants are asked to indicate the correct form, choosing between the 8 possible forms. The chance level is thus 12.5%, a lower level as compared with other instruments presented in literature. The subject's form perception ability is calculated as the mean of the correct answer for each level. In addition for each subject it will be possible to evaluate the percentage or the mean of the correct answer for each form. This kind of test is supposed to elicit the parvocellular system - ventral pathway because it's based on high spatial frequency stimuli and the subject is asked to make a *what task*. The use of luminance defined stimuli could cope with the criticism reported by Skottun and Skoyles (2011) regarding the use of contrast sensitivity tasks in order to elicit parvocellular functionality.

Raven's Colored Progressive Matrices (CPM; Raven, 1992):

The Raven's CPM is a common measure of basic cognitive functioning, quantifying a child's ability to form comparisons and to reason by analogy (Raven, Raven, & Court, 1962). The test comprises 36 items divided into three sets of 12 (A, Ab and B) in which items are ordered by increasing difficulty. Each item is presented as a colored pattern with a missing portion and 6 options from which to choose to fill in the missing element. Some items test the ability to complete a continuing pattern. Others require perception of the parts of the whole pattern as one gestalt on the basis of spatial relations. Finally, some of them require analogical reasoning.

Visual Acuity test

In order to avoid possible distortions of the data, the binocular visual acuity, with habitual correction, of the participants had been tested in two conditions of contrast at 3 m distance (2.5% and 100% contrast) by using LEA vision test (Repka, 2002).

4.3.3 **Data analysis**

In order to analyze the development of Motion and Form coherence perception abilities, descriptive indexes of accuracy had been evaluated using the accuracy scores of motion and form tests. Nonlinear regression analysis, using the psychophysical function described in the previous study, was conducted in order to fit the experimental data. The parameter W was estimated with an iterative method for nonlinear optimization: the sequential quadratic programming. The initial values for the parameter was specified as W=0.5. The model was determined using sum of squared residuals as a loss function.

The analysis of the parameter for the different age groups allowed to obtain information about the standard deviation of the distribution in the different age groups. A small W corresponds to a steeper curve, while a large W produced a flat curve. The use of a psychophysical function allowed the comparison of tests with different difficulty levels. An analysis of the normality parameters of the scores and the W parameters of the half-normal function were conducted.

Developmental profiles of motion coherence and form coherence ability were analyzed by using two generalized linear models (GZLM). The GZLMs were conducted considering as a dependent variable the parameter W, and the age group and the gender as fixed factors. The selected probability function was the “normal function” and the link function was the “identity function”.

To better investigate the relations between the two tests, a Generalized Estimating Equations test (GEE) was conducted, considering the two tests (Motion and Form) as within-subject factors and the age group and the gender as between-subject factors. The selected probability function was the “normal function” and the link function was the “identity function”.

Non-parametric percentiles and z-scores were calculated on accuracy scores for each of the age groups. To obtain a better estimation of the normative data the extreme scores were eliminated (scores who lies above the Q3 + 3*IQR are considered extreme scores).

4.1 Results

Eleven nonlinear regression analysis were conducted in the different age groups in order to estimate the best half-normal psychophysical function for the experimental data. In tables 7 and 8 are displayed the estimated parameter W (and S.E.) for the age groups. Furthermore, in tables 7 and 8 are displayed the means (and S.E.) of the accuracy for the age groups. As expected, with the increase of the age of the subjects, the accuracy score increases and the parameter W decreases.

The analysis of the distribution of the W parameters showed marked dissimilarities from normal distribution. In particular, regarding Motion coherence tests the distribution resulted right skewed (skewness=4.74 SE=0.12) and leptokurtic (kurtosis=24.13 SE=0.23) (Fig. 22). The Kolmogorov Smirnov test confirmed these results finding a significant difference with the normal distribution (Kolmogorov Smirnov test=6.92; $p<0.01$). Similar results were evidenced for Form coherence test (skewness=4.70 SE=0.11; kurtosis=48.02 SE=0.23; Kolmogorov Smirnov test=2.59; $p<0.01$) (Fig. 23). The two curves resulted to be thinner and with a longer right tail in comparison to normal distribution. Consequently, the results of this analysis suggest the use of non-parametric statistics in order to analyze the differences with age of the W parameters.

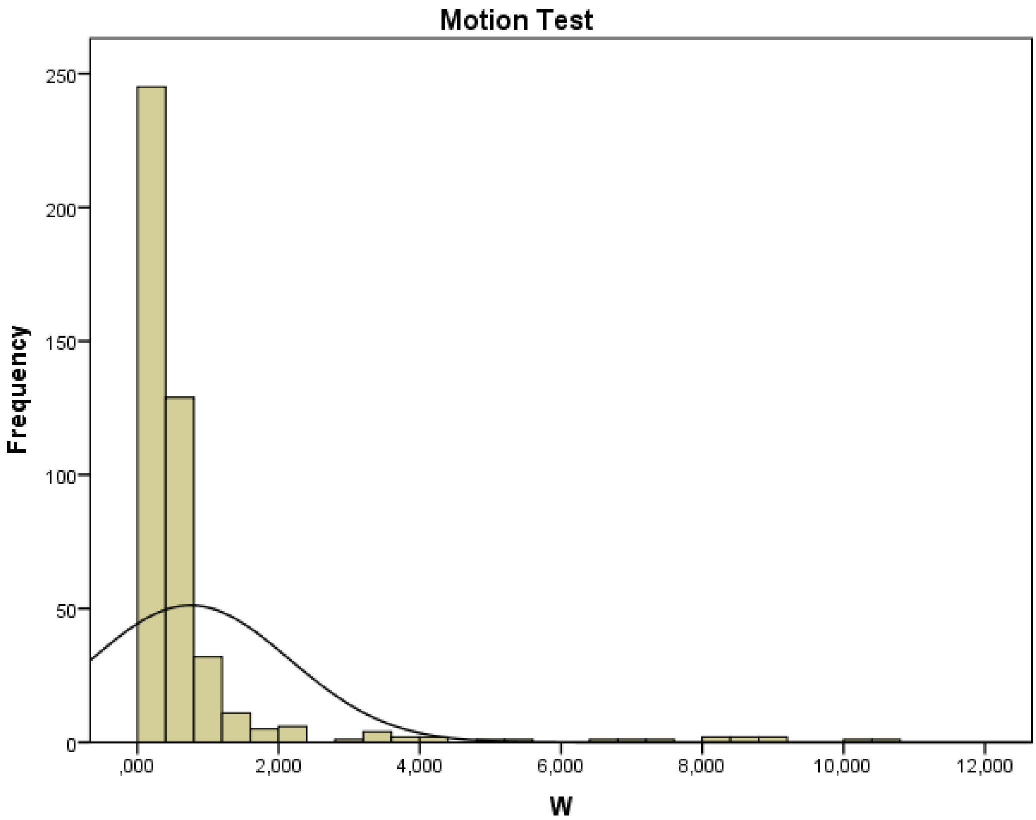

Fig. 22: Frequency distribution of W parameter in the Motion coherence test

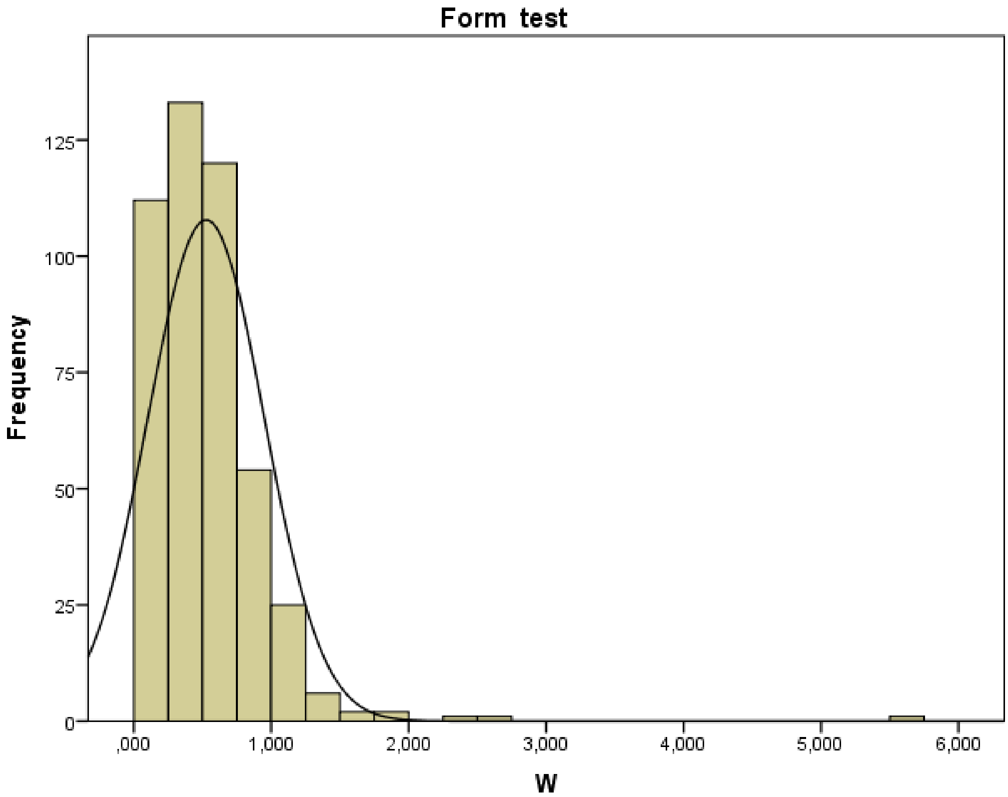

Fig. 23: Frequency distribution of W parameter in the Form coherence test

In order to investigate the effect of the age on the motion and form perception performance, two univariate GZLMs were conducted.

Regarding the Motion coherence effect (Tab. 7), the GZLM showed a significant age group effect ($Wald_{10}$=175.42 $p<0.01$), a non-significant gender effect ($Wald_{1}$=0.76 p=0.38) and a significant age group by gender interaction ($Wald_{10}$=20.46 p=0.03). In particular, the youngest male subjects (4 years) and the male adults performed better than females, while in the others age groups, males and females showed similar performances (Table 9). The analysis of simple orthogonal contrasts revealed that children of 4 and 5 years of age perform significantly poorer as compared to adults (both $p<0.01$), while starting from 6 years of age the W parameter didn't differ significantly from the adults' W.

The GZLM conducted on Form coherence test (Tab. 8) showed a significant age group effect ($Wald_{10}$=296.91 p<0.01), a non-significant gender effect ($Wald_1$=1.00 p=0.31) and age group by gender interaction effect ($Wald_{10}$=2.02 p=0.99) (Table 9). The analysis of simple orthogonal contrasts revealed that children from 4 to 9 years of age perform significantly poorer as compared to adults, while starting from 10 years of age the W parameter didn't differ significantly from the adults' W.

Table 7. Means of accuracy and W parameter of the Motion coherence tests in the different groups of age. Wald parameters and sig. of the simple contrast vs. adults.

Motion coherence test						
Age group	**Accuracy**	**S.E.**	**W**	**S.E.**	**Wald**	**Sig.**
4	.49	.04	1.26	.07	84.42	.00
5	.59	.03	.93	.05	30.75	.00
6	.69	.01	.44	.02	.24	.63
7	.69	.03	.44	.02	2.69	.10
8	.73	.02	.37	.02	.43	.51
9	.76	.02	.33	.01	.06	.81
10	.76	.02	.35	.01	.10	.75
11	.77	.02	.32	.01	.02	.89
12	.79	.02	.30	.01	.01	.94
13	.78	.03	.31	.02	.06	.80
Adults	.79	.02	.31	.01		

Table 8. Means of accuracy and W parameter of the Form coherence tests in the different groups of age. Wald parameters and sig. of the simple contrast vs. adults.

Form coherence test						
Age group	**Accuracy**	**S.E.**	**W**	**S.E.**	**Wald**	**Sig.**
4	.50	.02	1.00	.04	175.71	.00
5	.62	.02	.72	.03	48.17	.00
6	.54	.02	.63	.04	19.65	.00
7	.60	.02	.53	.03	12.07	.00
8	.64	.02	.46	.03	6.41	.01
9	.64	.02	.46	.03	7.15	.01
10	.68	.02	.35	.02	2.16	.14
11	.69	.02	.34	.02	2.03	.15
12	.69	.02	.35	.02	2.64	.10
13	.72	.02	.28	.02	.62	.43
Adults	.73	.01	.25	.01		

The Generalized Estimating Equations showed a significant kind of test (Motion vs. Form) effect ($Wald_1$=15.55 p<0.01), a significant age group effect ($Wald_{10}$=167.45 p<0.01), a significant test by age group effect ($Wald_{10}$=44.96 p<0.01), and a significant age group by gender effect ($Wald_{10}$=24.66 p=0.01). In particular, the two tests showed different rates of development in the different age. Youngest children perform better in Form recognition in comparison to Motion perception, however this ability develops slowly, converging to adult like levels later that motion perception ability (Fig. 24, Table 9).

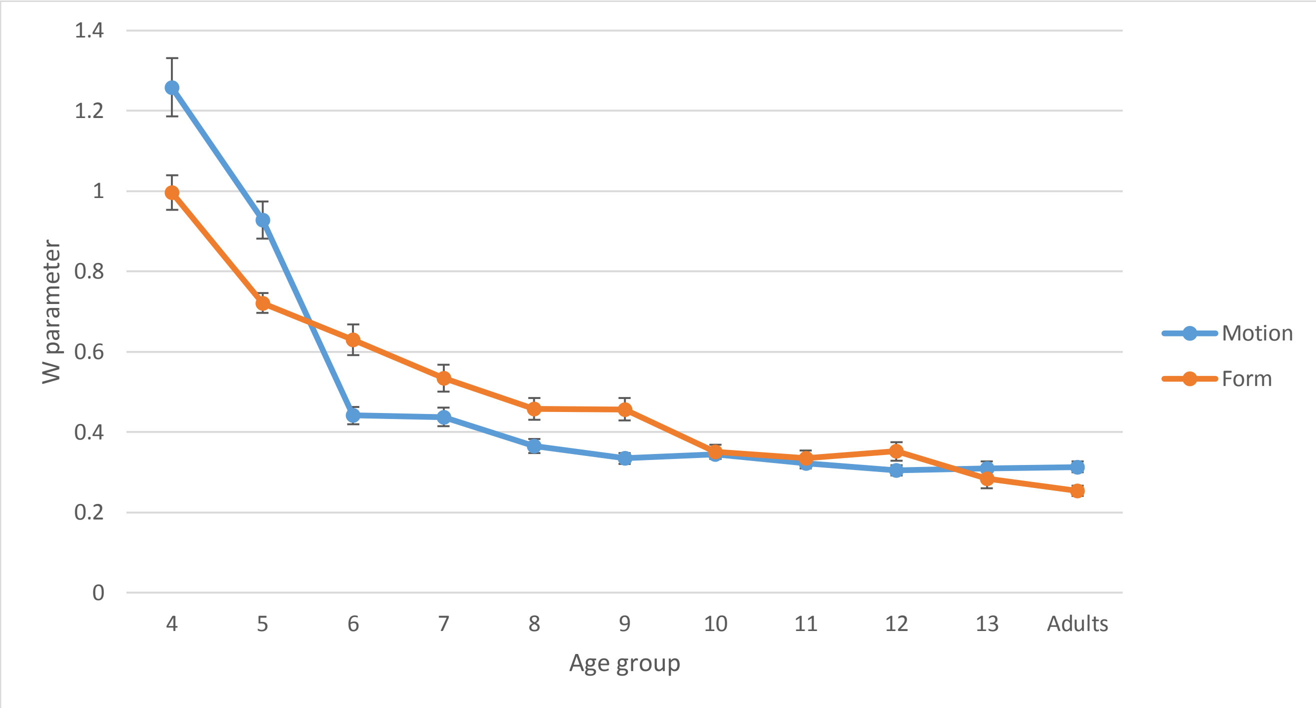

Figure 24 W parameter of the Motion and Form tests in the different groups of ages (and SE).

Table 9. Means (SE) of W parameter for males and females in the different groups of age.

	Motion W mean (SE)				**Form W means (SE)**			
Age group	**Males**		**Females**		**Males**		**Females**	
4	1.96	(0.25)	3.22	(0.26)	1.17	(0.07)	1.06	(0.07)
5	2.19	(0.28)	1.26	(0.24)	0.76	(0.07)	0.74	(0.06)
6	0.39	(0.38)	0.50	(0.31)	0.61	(0.10)	0.66	(0.08)
7	0.52	(0.28)	0.96	(0.30)	0.53	(0.07)	0.51	(0.08)
8	0.44	(0.25)	0.50	(0.28)	0.46	(0.07)	0.43	(0.08)
9	0.37	(0.24)	0.35	(0.28)	0.50	(0.06)	0.41	(0.08)
10	0.36	(0.21)	0.38	(0.24)	0.39	(0.06)	0.32	(0.06)
11	0.37	(0.26)	0.30	(0.27)	0.35	(0.07)	0.37	(0.07)
12	0.34	(0.27)	0.31	(0.31)	0.39	(0.07)	0.37	(0.08)
13	0.40	(0.40)	0.35	(0.28)	0.39	(0.11)	0.26	(0.07)
Adults	0.19	(0.31)	0.42	(0.21)	0.25	(0.08)	0.27	(0.06)

Furthermore, in order to obtain the normative data for Motion and Form coherence tests, the Z-scores and the non-parametric percentiles were calculated for each group of ages. The extreme scores, who lied above the third interquartile plus three times the interquartile range, were excluded (N=2 for the Form test and N=14 for the Motion test). The comparison between the non-parametric percentiles and the second standard deviation below the mean were displayed in tables 10 and 11. As could be seen in some group of age the two parameters (the 2.3th centiles and the Z-score - 2 SD) appeared very similar, while in other age groups the two indexes resulted to be markedly different.

Table 10. Z score transformation (-2 SD) and non-parametric percentiles calculated in the different age groups in Motion coherence test

Motion Coherence test											
			Z-score				**Percentiles**				
Age group	**Mean**	**SD**	**- 2 SD**	**2.3**	**5**	**10**	**25**	**50**	**75**	**90**	**95**
4	0.49	0.24	0.00	0.10	0.15	0.18	0.25	0.52	0.70	0.82	0.88
5	0.63	0.21	0.20	0.14	0.24	0.30	0.45	0.68	0.79	0.90	0.95
6	0.69	0.10	0.50	0.47	0.50	0.58	0.62	0.68	0.76	0.81	0.88
7	0.72	0.10	0.52	0.52	0.52	0.55	0.65	0.74	0.80	0.86	0.90
8	0.76	0.11	0.54	0.49	0.52	0.58	0.69	0.77	0.84	0.89	0.92
9	0.78	0.09	0.60	0.59	0.59	0.64	0.72	0.78	0.84	0.88	0.94
10	0.76	0.12	0.53	0.48	0.54	0.61	0.68	0.76	0.85	0.92	0.93
11	0.77	0.10	0.57	0.56	0.56	0.62	0.71	0.80	0.86	0.91	0.93
12	0.80	0.09	0.61	0.51	0.59	0.67	0.76	0.80	0.88	0.91	0.92
13	0.79	0.13	0.54	0.41	0.46	0.62	0.74	0.83	0.88	0.93	0.98
Adults	0.79	0.12	0.54	0.52	0.56	0.59	0.71	0.82	0.89	0.92	0.98

Table 11. Z score transformation (-2 SD) and non-parametric percentiles calculated in the different age groups in Form coherence test

Form Coherence test												
			Z-score				**Percentiles**					
Age group	**Mean**	**SD**	**- 2 SD**	**2.3**	**5**	**10**	**25**	**50**	**75**	**90**	**95**
4	0.51	0.13	0.26	0.28	0.32	0.34	0.43	0.50	0.60	0.68	0.74
5	0.62	0.11	0.40	0.39	0.44	0.50	0.55	0.61	0.68	0.80	0.83
6	0.55	0.10	0.36	0.34	0.35	0.41	0.48	0.57	0.59	0.68	0.71
7	0.60	0.11	0.38	0.43	0.43	0.46	0.52	0.59	0.68	0.75	0.81
8	0.64	0.11	0.41	0.41	0.46	0.49	0.55	0.64	0.71	0.79	0.84
9	0.64	0.12	0.40	0.30	0.44	0.47	0.57	0.66	0.75	0.80	0.81
10	0.68	0.12	0.45	0.43	0.46	0.52	0.60	0.71	0.77	0.82	0.86
11	0.69	0.10	0.49	0.48	0.55	0.57	0.60	0.71	0.75	0.84	0.88
12	0.69	0.11	0.46	0.43	0.51	0.54	0.60	0.68	0.76	0.85	0.90
13	0.72	0.12	0.48	0.48	0.51	0.57	0.62	0.72	0.82	0.89	0.90
Adults	0.73	0.08	0.56	0.52	0.56	0.61	0.68	0.73	0.80	0.82	0.87

4.4 **Conclusions**

The analysis conducted on the results of the Motion and Form coherence tests showed that the two abilities clearly increases with age in the participants. Furthermore, the use of the psychophysical function instead of the raw accuracy scores allowed the comparison between tests with different signal/noise ratios. In fact, both the motion and form tests and the preschool and the school age tests presented different coherence levels. The analysis of the development ratios of Motion and form perception abilities revealed different tendencies. In particular, the analysis of the development trends revealed that in the age range 4 to 6 the motion perception presented a faster development as compared to the form discrimination. In fact, even if motion perception resulted less efficient than form discrimination in the younger children, in the age of 6 this trend reverses evidencing a better discrimination ability for motion perception as compared to form perception. Statistical analysis confirmed the fast development of this ability, finding that motion perception ability did not differ from adult levels starting from the age of 6. This result confirmed the previous findings in literature that evidenced an early development of the dorsal functionality (Parrish et al., 2005; Grill-Spector, Golarai, & Gabrieli, 2008). In particular, a study conducted by Atkinson and colleagues (2003) evidenced that form coherence showed a very light improvement from 4- to 6-years-old, while motion coherence showed a much more marked improvement in the same age. Despite this difference in the rate of development of the two functions, adult values for the motion and form perception thresholds were similar. The characteristics of the stimulus could probably be linked to this results. E.g.. studies that used slow dot speeds could found a slower maturation of this ability (see Narasimhan & Giaschi, 2012). The analysis of the literature shows that the structure of the stimuli and their parameters, in particular dot speed and dot density, vary consistently across the different studies.

The developmental trend of the form discrimination ability resulted to be more linear as compared to the motion perception. Our result showed that the ability of the children in discriminating forms slowly increases during the entire childhood. Statistical analysis revealed that children ability in form discrimination did not reach adult like levels before the 10 years of age. This finding fall between the study that found an earlier maturation (around 7 years: Gunn et al., 2002; Armstrong, Maurer, & Lewis, 2009) and the others that found a late development (around 12 years, Parrish, Giaschi, Boden & Dougherty, 2005).

The results confirmed that the ability to integrate local information into a global pattern of motion or form perception could be considered high level visual function, that are subject to a protracted development that does not end in infancy but continue during the years of childhood.

Given the characteristic developmental trends of the investigated visual function it seems useful, in particular for clinical applications, to define the normative scores of the Motion and Form coherence tests. The use of the non-parametric percentiles allowed to face the problem of the distribution of the accuracy scores. As discussed in literature (Losito, Tressoldi & Cornoldi, 2014), the use of the transformation in Z scores with a non-normal distribution of the scores could determine a distortion of the limit of normality. Also in our data, this phenomenon could be observed in several age groups, in which the computed Z-score limit of the -2 SD below the mean resulted markedly different as compared to the non-parametric percentiles calculated on the collected data. The use of the non-parametric approach in fact allows to overcome the problem of the distribution of the data. The percentiles are calculated directly on the frequencies of the scores. However, it's important to underline that this approach requires an adequate number of subject and that it is more susceptible to the influence of the outliers and the extreme values. For this reason, in order to obtain a more accurate estimation of the normative scores, the extreme values had been eliminated from every group of ages. Using the non-parametric approach had been possible to define the normative scores; a subject that performs worse than the 2.3^{th} or the 5^{th} percentile as compared to his class of age could be consider to evidence a deficit in the motion perception or in the form discrimination ability.

The results of this study showed that the use of an appropriate psychophysical function allowed to analyze the developmental trends of the Motion and Form perception abilities, comparing subject's abilities in different tests with different coherence proportions. The definition of the developmental trends and the normative scores of the Motion and Form coherence perception abilities could reveal very useful in a clinical application of the two tests. It will be possible to identify a deficit in these abilities by using these two simple and fast computerized tests.

5. Experiment 4 – The study of motion and form perception accuracy in children with Noonan syndrome, 22q11.2 deletion syndrome and controls

Several studies have investigated whether dorsal pathway is more vulnerable than the ventral during development and whether ventral and dorsal streams develop at different rates in clinical population. Many results indicated that a variety of developmental disorders could manifest specific deficit in motion processing. Indeed, abnormalities in the dorsal stream are characteristic of developmental disorders such as Williams and X-fragile syndromes but are also observed in autism or could be a consequence of perinatal pathological events (hemiplegia, perinatal brain anomalies following very premature birth). These findings suggested the presence of a general dorsal-stream vulnerability in many different conditions of abnormal human development (Atkinson et al., 1997; Braddick, Atkinson, & Wattam-Bell, 2003). Accordingly, the visual deficits (e.g., problems with motion perception, visual-spatial attention, depth perception, visual-motor control, and development of graphomotor skills) that are found to be prevalent in prematurely born children could indicate an impairment or a dysfunction in the dorsal stream (Downie et al., 2003; Jakobson et al., 2001). A body of evidence concerning preterm children (Atkinson & Braddick, 2007; Birtles et al., 2007) found that the development of dorsal stream functions may be more severely impaired as compared to ventral stream functionality. These studies found that children born prematurely with very low birthweight exhibited marked deficits in the ability to detect coherent global motion, a skill thought to depend on the functional integrity of the MT complex (Newsome & Pare; 1988; Schenk & Zihl, 1997), a key area in the dorsal stream (Schenk, Ellison, Rice, & Milner, 2005).

A study conducted by Atkinson and Braddick led to the supposition that visual-spatial dorsal functions are specifically vulnerable and more less frequently compensate than ventral functions (Atkinson & Braddick, 2007).

Moreover, the results from studies of children with Noonan syndrome (NS) showed a different pattern of impairment from what is observed in other developmental and genetic disorders. NS deficits in visual functionality seem to be consistent with a deficit of the ventral pathway (Alfieri et al., 2011) and with results already observed in patients with developmental dyspraxia (O'brien. 2002).

The dissociation between dorsal and ventral abilities has not been fully elucidated. The data suggesting which of the two systems shows a greater vulnerability have not been completely clarified in developmental disorders and genetic syndromes.

The characterization of ventral and dorsal stream skills in genetic syndromes could allowed to better understand the relation between genetic features and behavioral phenotypes.

NS is an autosomal dominant multisystem disorder with an estimated prevalence of 1 in 1000–2500; mutations in one of twelve genes (*PTPN11*, *SOS1*, *KRAS*, *NRAS*, *RAF1*, *BRAF*, *MEK1*, *SHOC2*, *CBL, RIT1*, *SOS2*, and *LZTR1*) alter the encoding of proteins with roles in the RAS–MAPK pathway and lead to pathway dysregulation (Tartaglia & Gelb, 2010). It is characterized by dysmorphic facial features, cardiac defects, developmental delay, multiple skeletal anomalies, proportionate short stature, hematologic abnormalities, cryptorchidism, ophthalmologic impairments, variable cognitive deficit and learning difficulties (Noonan, 1994). Only a few studies investigated visual-spatial and visual-perceptual abilities in NS. In particular, a study by Alfieri and colleagues (2011) highlighted a ventral deficit in the visual system. Furthermore, a previous study by the same authors (Alfieri, 2008) showed that visual abilities were frequently altered in NS.

The 22q11.2 deletion syndrome (22q11.2DS) is a genetic disorder caused by microdeletions on chromosome 22q11.2, with population prevalence of about 1:4000 births (Wilson et al., 1993; Kobrynski & Sullivan, 1993). The 22q11.2DS has an extremely expansive phenotypic spectrum and multisystem manifestations. More than 180 clinical features have been described, including congenital heart defects, velopharyngeal anomalies, craniofacial features, cognitive deficits and high rates of psychiatric morbidity (Shprintzen, 2000). Although some controversies concerning this topic persist (Howley et al., 2012), previous reports documented deficits in visual-spatial and visual-motor abilities in patients with 22q11.2DS with no relevant differences in dorsal and ventral stream tasks (Vicari et al., 2012; Swillen et al., 1999).

5.1 **Aim**

The aim of the present study is to evaluate if the Motion and Form coherence test are able to identify specific deficits in clinical populations. In particular, this research aims to compare the functionality of the dorsal and the ventral streams in two populations affected by different genetic disorders (NS and 22q11.2DS) in order to better understand the relationship between the differential genotype and motion and form perception vulnerability.

The functionalities of the dorsal and ventral visual stream were evaluated using the Motion Coherence test (mainly mediated by the dorsal pathway) and the Form Coherence test (mainly mediated by the ventral pathway), in children with NS and with 22q11.2DS compared with typically developed controls.

If the dorsal stream was more vulnerable than the ventral stream and abnormalities in the dorsal stream functioning were characteristic of developmental disorders in general, it could be expected that in both syndromic groups the performance in the Motion Coherence task would be lower than the Form Coherence task one. Otherwise, if the ventral stream was more at risk than the dorsal stream, we would observe in both syndromic groups a lower performance in the Form Coherence task than in the Motion Coherence task.

The study was conducted in collaboration with the Neuroscience, Child Neuropsychiatric Unit, Bambino Gesù Children's Hospital, IRCCS, Rome and Center for Rare Diseases, Department of Pediatrics, Polo Salute Donna e Bambino, Fondazione Policlinico Universitario A. Gemelli, Catholic University of Rome.

5.2 **Methods**

5.2.1 **Participants**

Visual-spatial abilities were evaluated in 19 participants with NS and in 20 participants with 22q11.2DS recruited from the Neuropsychiatric Unit of the Bambino Gesù Children's Hospital (Rome, Italy) and from the Department of Pediatrics of the Catholic University (Rome, Italy). Fifty-five chronological age-matched controls ($F_{(2, 91)}$=2.06, p=0.13, ηp^2 = 0.04) were recruited from primary school. A general description of the groups (i.e. sex, chronological age, and IQ) is reported in table 12.

Table 12 Description of three groups: numerosity, sex, chronological age and IQ

Groups (N)	**NS (19)**	**22q11.2DS (20)**	**Controls (55)**
Sex (m/f)	7/12	10/10	36/19
Chronological Age (mean) **(SE)**	8.8 (0.44)	9.8 (0.67)	8.8 (0.20)
IQ (mean) **(SE)**	101 (3.56)	83 (2.5)	103 (2.85)

5.2.2 **Measures and procedures**

The evaluation was conducted individually in 2/3 sessions on different days. The tasks were presented to each participant in a pseudo-randomized order.

The study was conducted according to the Declaration of Helsinki. The parents of participants gave written informed consent.

Intelligence evaluation and visual-motor integration assessment

General intelligence was evaluated using the Colored Progressive Matrices-CPM (Raven, 1962). The test gives a measure of non-verbal intelligence and assesses the capacity to reason by analogy, and to understand and form perceptual relations. The score is expressed in numerical Intelligence Quotient (IQ).

The Visual-Motor Integration Test-VMI (Beery, Buktenica & Beery, 1997) measures the extent to which individuals can integrate their visual and motor abilities. The result is expressed in Standard Score (SS stand).

Form perception

The ability to discriminate forms is measured using the Form Coherence test.

The stimulus is made up of 1050 static high luminance dots (luminance 51.0 cd/m2) presented on a black background (0.2 cd/m2). The signal dots are spatially aligned (i.e. with the same horizontal and vertical distance between the dots) in a circular frame creating a recognizable form (Figure 1), while the noise dots are randomly positioned, non-aligned, within the frame. The obtained form is selected within eight possible different simple shapes. There are four geometric/abstract shapes (circle, square, triangle and star) and four concrete/easily recognizable figures (house, bear, doll and cup). Five levels of coherence are presented, starting from a first level in which all the dots constituting the form are spatially aligned; in the subsequent four levels the number of coherent dots decreases by 2 db (37%) and the number of non-aligned noise dots increases. The form lasts for 3 sec. The subject is asked to identify the presented form from among the eight possible forms. The mean number of correct responses in each difficulty level is used as a measure of form discrimination ability.

Motion perception

Motion perception was evaluated using the Motion coherence test. Participants sit in front of the monitor located in an experimental room in which the light is dimmed. A training session of twelve trials serves as a short practice for the participant. The test consists of forty trials. The stimulus consists of 150 high luminance dots (luminance 51.0 cd/m2) moving within a circular frame on a black background (0.2 cd/m2). During the test the coherent dots have a constant speed of 6.1°/s. and are moving in one of the eight directions of the space (randomly chosen among 4 cardinal and 4 oblique points) for 2000 ms. In order to avoid tracking, each dot has a limited lifetime of 4 animation frames (duration = 200 ms). The task consists of five levels of coherence in which noise is gradually introduced by means of Brownian moving dots. In the first level, all the dots are moving coherently in a specific direction (100% coherence), then, in the subsequent four levels, the coherence decreases exponentially by 2 db (37% coherence) and the number of Brownian noise dots increases. The participant is asked to detect the correct direction of coherent moving dots. The mean number of correct detections for each level is recorded.

5.2.3 **Data analysis**

A one-way ANOVA was used in order to compare the average scores obtained in CPM and VMI by the participants with NS, participants with 22q11.2DS, and Controls.

Averages of correct responses obtained at Form and Motion Coherence Tasks were calculated using ANCOVA, with group as a between factor, levels of task (from I to V) as within factor, and age, CPM and VMI scores as covariates. Unequal N HSD post hoc test was used. The significance level was established at $p < 0.05$.

5.3 **Results**

5.3.1 **Cognitive and visual-motor abilities**

Analysis of the CPM score showed a main effect of Group ($F_{(2, 62)}=13.65$, $p <0.01$, $\eta p^2 = 0.305$) since the score obtained by the group with 22q11.2DS was significantly lower than that of the group with NS (22q11.2DS vs NS: $p<0.01$) and that of the Controls (22q11.2DS vs Controls: $p < 0.01$). The two latter groups did not differ from each other (NS vs Controls: $p = 0.79$).

Analysis of the VMI score showed a main effect of Group ($F_{(2, 59)} = 28.99$, $p < 0.01$, $\eta p^2 = 0.495$). The mean of scores of the group with NS (81 SS stand SE=12.9) did not differ from that of the group with 22q11.2DS (84.22 SS stand SE=13.2; NS vs 22q11.2DS: $p = 0.74$) and both groups showed lower scores than Controls (108 SS stand SE=12.6; 22q11.2DS vs Controls: $p < 0.01$; NS vs Controls: $p < 0.01$).

Since the three groups were not comparable for general intelligence and visual-motor abilities, to control for possible effects CPM and VMI scores were included as covariates in the analysis of Form Coherence test and Motion Coherence test.

5.3.2 **Experimental tasks**

The results of the ANCOVA on the scores obtained at Form Coherence test showed a main Group effect ($F_{(2,57)}=8.21$, $P < 0.01$, $\eta p^2 = 0.223$; Figure 25). The mean of correct responses in the NS group (0.54, SE = 0.03) and in the 22q11.2DS group (0.45, SE = 0.03) did not differ (NS vs 22q11.2DS: $p = 0.24$), and both were significantly lower than Controls group's mean (0.70, SE = 0.02; Controls vs NS: $p < 0.01$; Controls vs 22q11.2: $p < 0.01$). The comparison of the groups in each level of the Form Coherence test showed no differences between NS and Control groups in levels I, IV, V ($p > 0.1$) with regard to the mean correct responses. Conversely, the NS group performed significantly lower than Controls (p always < 0.01) in levels II and III. The mean of correct responses of the group with 22q11.2DS did not differ from the Controls in levels I and V ($p > 0.1$) but was significantly lower than Controls in levels II, III, IV (p always < 0.01).

Considering the intra-group analysis in the Form Coherence test (Fig. 25), Controls progressively reduced the mean of correct responses passing from level I to levels II and III (I vs II; II vs III; I vs III; p always < 0.05), and at level V the mean of correct responses were even lower than at level III ($p < 0.01$). Conversely, the mean of correct responses of the group with NS decreased passing from level I to level II (I vs II: $p < 0.01$) and from level I to level III (I vs III: $p < 0.01$), but did not differ passing from level III to levels IV and V (III vs IV; IV vs V; p always > 0.1). Similarly, in the group with 22q11.2DS the mean of correct responses differed passing from level I to level II (I vs II: p < 0.01) and from level I to level III (I vs III: p < 0.01), but did not differ passing from level III to levels IV and V (III vs IV; IV vs V; p always > 0.1).

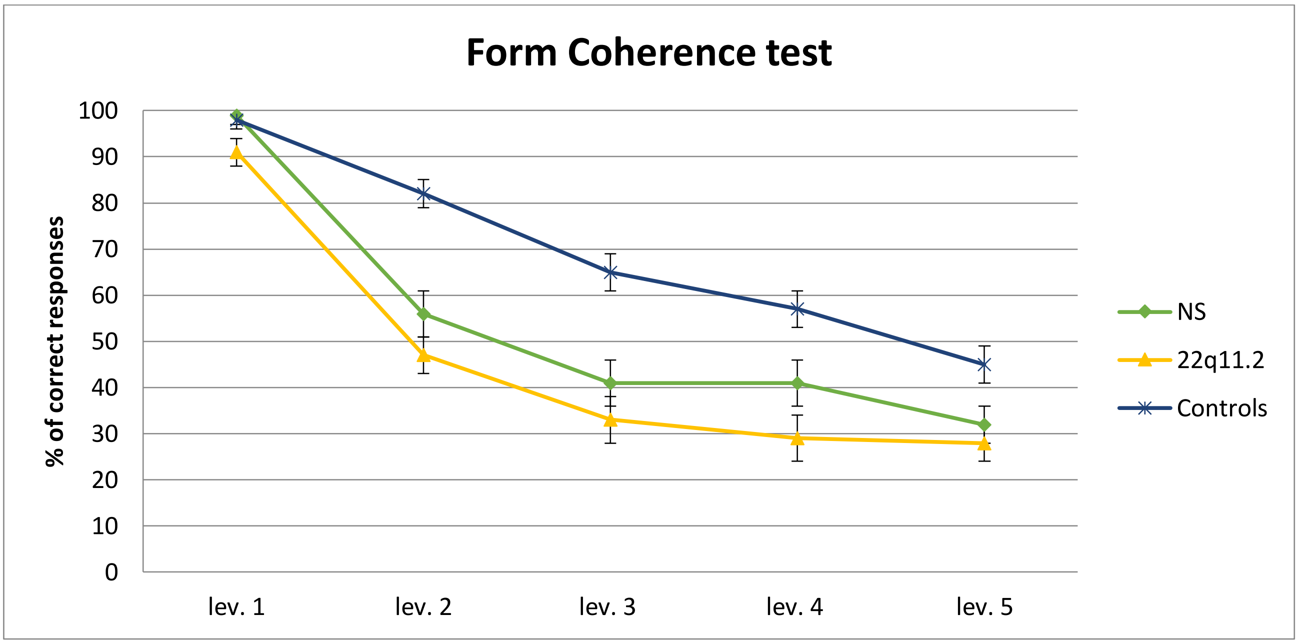

Figure 25 - Percentages of correct responses (S.E.) of the three groups in all five levels of the Form Coherence task.

Interestingly, different results were obtained from the analysis of covariance on the scores of the Motion Coherence test (Figure 26). Groups differed in the mean of correct responses ($F_{(2,57)} = 4.296$, $p = 0.01$, $\eta p^2 = 0.130$). The group with 22q11.2DS (0.38, SE = 0.04) performed significantly poorer than the group with NS (22q11.2DS vs NS: $p = 0.01$) and Controls (22q11.2DS vs Controls: $p < 0.01$). The NS group and the control group did not significantly differ (respectively, 0.56, SE = 0.04 and 0.57, SE = 0.03; NS vs Controls: $p > 0.99$).

Intra-group analysis of the Motion Coherence test revealed similar trends for the Controls and the group with NS. Indeed, in both groups the mean of correct responses differed passing from level I to level III and from level III to level V (p always < 0.01). For the group with 22q11.2DS the mean of correct responses differed passing from level I to level III ($p < 0.01$), but the performance did not differ passing form level III to level V ($p > 0.1$).

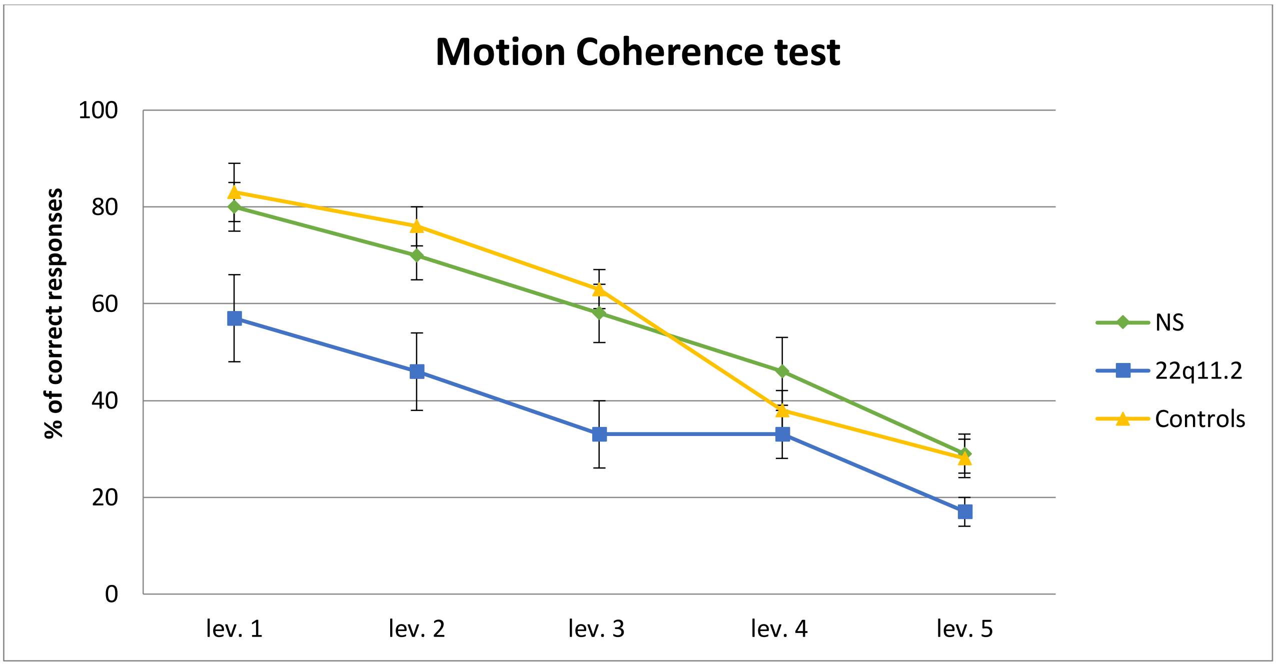

Figure 26 - Percentages of correct responses (S.E.) of the three groups in all five levels of the Motion Coherence task.

5.4 **Discussion**

Motion and Form coherence tests result to be useful instruments to recognize specific perceptual deficits in clinical populations. According to the literature on visual-spatial processing, the dorsal and the ventral streams appear to differ in their developmental trajectories and their levels of vulnerability seem to be related to different neurodevelopmental conditions. As previously noted, several studies (Braddick, Birtles, Wattam-Bell, & Atkinson, 2005; Wattam-Bell et al., 2010) highlighted that dorsal pathway is likely to be more susceptible than ventral pathway to the damage due to developmental factors. Therefore, it is possible that, especially in perinatal period, the motion-processing systems may be highly vulnerable to neurodevelopmental or experiential factors.

However, other studies (Parrish et al., 2005; Simic & Rovet, 2016) showed a similar vulnerability patterns in ventral and dorsal stream functions in specific developmental disorders, for example, congenital hypothyroidism (Simic & Rovet, 2016).

Comparing children with different syndromic conditions, the present study allowed us to investigate whether ventral and dorsal stream functions are equally vulnerable in developmental disorders or whether they are related to the specific syndrome's genotype.

Our results indicated that the two groups of children with genetic syndromes did not differ in the scores obtained in the Form Coherence task. In fact, both groups performed lower than the control group in form recognition. Conversely, in the Motion Coherence task the performance achieved by children with NS syndrome and 22q11.2DS significantly differed. The scores obtained by the group of children with NS were higher than those obtained by children with 22q11.2DS and did not differ from those of the control group.

Specifically, in the Form Coherence task, children with NS and with 22q11.2DS always showed a lower mean of correct responses than controls and, from the third level of the task (level III) their scores did not vary according to the increasing difficulty of the task. Conversely, controls showed a gradual decrease in the mean of correct responses passing from level I (the easiest) to level V (the hardest).

In the Motion Coherence test, children with NS and controls had an analogous performance, characterized by a progressive decrease of correct responses with the increase of the test difficulty (passing from level I to level V). Conversely, as in the Form Coherence task, children with 22q11.2DS always showed a lower mean of correct responses than controls and then children with NS. From level III of the task onwards, children with 22q11.2DS could no longer detect the correct direction of coherent moving dots.

Therefore, the dissociation between the performances achieved by the two syndromic groups in the Form and Motion Coherence tests seem to indicate that ventral and dorsal stream functions are not

equally vulnerable in the two genetic conditions. The performance appears to be related to the specific genotype of the syndrome.
Results on the Form and Motion Coherence test (impaired ability in both syndromic groups VS. preserved abilities in the group with NS and deficits in the group with 22q11.2DS) could be interpreted as a specific outcome of the genotype, caused by neurobiological factors resulting from genetic abnormalities and expressed in abnormal brain maturation. This result in children with 22q11.2DS agreed with many findings in literature (Vicari et al., 2012; Swillen et al., 1999), documenting that dorsal function deficit is a core deficit in this syndromic group, persisting also in individuals with 22q11DS without intellectual disability (Vicari et al., 2012). Therefore, our results showed a selective impairment in the Motion Coherence task, also when the intellectual and the visual-motor integration abilities were taken into account.

Moreover, the present results cannot be interpreted as just an effect of intellectual abilities, given the differences between the IQ scores of the two syndromic groups. Indeed, both NS and the 22q11DS groups showed a deficit in the Form Coherence task even if they differed with regard to IQ. Nevertheless, the analysis of variance, controlled for CPM scores, indicated that the differences found between the groups also persisted when this source of variability was taken into account.
Therefore, the presence of a specific deficit in the ventral stream of children with NS seemed to be related to the specific genotype and dependent on the etiology of the syndrome, supporting the concept of an etiological specificity of the behavioral phenotype and brain development.
Similarly, these findings cannot be interpreted as a result of the visual-motor difficulties documented in both syndromic groups. The analysis on VMI scores revealed a significantly lower score of both syndromic groups compared to controls. The dissociation found in the analysis of the Motion Coherence task between the group with NS and the group with 22q11DS, controlled for VMI score, demonstrated that visual-motor abilities did not significantly affect performance in the Motion Coherence task.

Functional neuroimaging studies that compare populations with genetic syndromes of different etiologies, and look directly at the correlation between behavioral phenotype and brain functionality, will be necessary to clarify the relationship between cognitive abilities and brain development. Further studies in children using magnetic resonance may also be crucial for identifying abnormalities in the ventral stream as documented by the tractography study conducted in adults with 22q11DS (Kikinis et al., 2012).

Moreover, studies including a control group of children matched for mental age (in addition to chronological age) will be necessary to fully understand the role of intellectual abilities in dorsal and ventral stream tasks.

In conclusion, the results of this study confirm the applicability of Motion and Form coherence tests to different clinical populations. The use of these test allowed to identify specific deficits in the functionalities of the motion perception and form discrimination abilities.

6. References

Ahsanullah, M., Kibria, B. G., & Shakil, M. (2014). *Normal and student's t distributions and their applications.* Paris: Atlantis Press.

Alfieri, P., Cesarini, L., De Rose, P., Ricci, D., Selicorni, A., Menghini, D., & Zampino, G. (2011). Visual processing in Noonan syndrome: dorsal and ventral stream sensitivity. *American Journal of Medical Genetics Part A*, *155*(10), 2459-2464.

Alfieri, P., Cesarini, L., Zampino, G., Pantaleoni, F., Selicorni, A., Salerni, A., & Staccioli, S. (2008). Visual function in Noonan and LEOPARD syndrome. *Neuropediatrics*, *39*(06), 335-340.

Allen, H. A., Humphreys, G. W., Colin, J., & Neumann, H. (2009). Ventral extra-striate cortical areas are required for human visual texture segmentation. *Journal of Vision*, *9*(9), 1–14.

Armstrong, V., Maurer, D., & Lewis, T. L. (2009). Sensitivity to first-and second-order motion and form in children and adults. *Vision research*, *49*(23), 2774-2781.

Atkinson, J., & Braddick, O. (2007). Visual and visuocognitive development in children born very prematurely. *Progress in brain research*, *164*, 123-149.

Atkinson, J., Braddick, O., Anker, S., Curran, W., Andrew, R., Wattam-Bell, J., & Braddick, F. (2003). Neurobiological models of visuospatial cognition in children with Williams syndrome: measures of dorsal-stream and frontal function. *Developmental neuropsychology*, *23*(1-2), 139-172.

Atkinson, J., Braddick, O., Rose, F. E., Searcy, Y. M., Wattam-Bell, J., & Bellugi, U. (2006). Dorsal-stream motion processing deficits persist into adulthood in Williams syndrome. *Neuropsychologia*, *44*(5), 828-833.

Atkinson, J., Braddick, O., Rose, F. E., Searcy, Y. M., Wattam-Bell, J., & Bellugi, U. (2006). Dorsal-stream motion processing deficits persist into adulthood in Williams syndrome. *Neuropsychologia*, *44*(5), 828-833.

Atkinson, J., King, J., Braddick, O., Nokes, L., Anker, S., & Braddick, F. (1997). A specific deficit of dorsal stream function in Williams' syndrome. *Neuroreport*, *8*(8), 1919-1922.

Beason-held, L. L., Purpura, K. P., Van Meter, J. W., Azari, N. P., Mangot, D. J., Optican, L. M., & Rapoport, S. I. (1998). PET reveals occipitotemporal pathway activation during elementary form perception in humans. *Visual neuroscience*, *15*(03), 503-510.

Beery, K. E., Buktenica, N. A., & Beery, N. A. (1997). *The Beery-Buktenica developmental test of visual-motor integration: VMI, with supplemental developmental tests of visual perception and motor coordination: administration, scoring and teaching manual*. Modern Curriculum Press.

Benassi, M., Rydberg, A., Belli, V., & Bolzani, R. (2003). Luminance and chromatic motion detection in dyslexia. *Perception ECVP abstract*, *32*.

Bertenthal, B. I. (1993). *Infants' perception of biomechanical motions: Intrinsic image and knowledge-based constraints*. In *Visual perception and cognition in infancy* (pp. 175-214). Hillsdale: Laurence Erlbraum.

Bertone, A., Hanck, J., Guy, J., & Cornish, K. (2010). The development of luminance-and texture-defined form perception during the school-aged years. *Neuropsychologia*, *48*(10), 3080-3085.

Birtles, D. B., Braddick, O. J., Wattam-Bell, J., Wilkinson, A. R., & Atkinson, J. (2007). Orientation and motion-specific visual cortex responses in infants born preterm. *Neuroreport*, *18*(18), 1975-1979.

Blake, R., & Shiffrar, M. (2007). Perception of human motion. *Annual Review of Psychol*ogy, *58*, 47-73.

Boring, E. G. (1942). *Sensation and Perception in the History of Experimental Psychology by Edwin G. Boring*. Appleton-Century-Crofts.

Bottarelli E., & Parodi S. (2003) Un approccio per la valutazione della validità dei test diagnostici: le curve R.O.C. (Receiver Operating Characteristic). *Annali Facoltà Medicina Veterinaria di Parma*, *23,* 49-68.

Braddick, O. J., O'Brien, J. M. D., Wattam-Bell, J., Atkinson, J., & Turner, R. (2000). Form and motion coherence activate independent, but not dorsal/ventral segregated, networks in the human brain. *Current Biology*, *10*(12), 731-734.

Braddick, O., & Atkinson, J. (2007). Development of brain mechanisms for visual global processing and object segmentation. *Progress in brain research*, *164*, 151-168.

Braddick, O., & Atkinson, J. (2011). Development of human visual function. *Vision research*, *51*(13), 1588-1609.

Braddick, O., Atkinson, J., & Wattam-Bell, J. (2003). Normal and anomalous development of visual motion processing: motion coherence and 'dorsal-stream vulnerability'. *Neuropsychologia*, *41*(13), 1769-1784.

Braddick, O., Birtles, D., Wattam-Bell, J., & Atkinson, J. (2005). Motion-and orientation-specific cortical responses in infancy. *Vision research*, *45*(25), 3169-3179.

Brouwer, A. M., Brenner, E., & Smeets, J. B. J. (2002). Perception of acceleration with short presentation times: Can acceleration be used in interception?. *Perception & Psychophysics*, *64*, 1160–1168.

Bruce, V., Green, P. R., & Georgeson, M. A. (2003). *Visual perception: Physiology, psychology, & ecology*. Hove, UK: Psychology Press.

Burr, D., & Thompson, P. (2011). Motion psychophysics: 1985–2010. *Vision research*, *51*(13), 1431-1456.

Casagrande, V. A., Yazar, F., Jones, K. D., & Ding, Y. (2007). The morphology of the koniocellular axon pathway in the macaque monkey. *Cerebral Cortex*, *17*(10), 2334-2345.

Cornelissen, P. L., Hansen, P. C., Hutton, J. L., Evangelinou, V., & Stein, J. F. (1998). Magnocellular visual function and children's single word reading. *Vision research*, *38*(3), 471-482.

De Vries, H. L. (1948). Brownian movement and hearing. *Physica*, *14*(1), 48-60.

Demb, J. B., Boynton, G. M., Best, M., & Heeger, D. J. (1998). Psychophysical evidence for a magnocellular pathway deficit in dyslexia. *Vision research, 38*(11), 1555-1559.

Downie, A. L., Jakobson, L. S., Frisk, V., & Ushycky, I. (2003). Periventricular brain injury, visual motion processing, and reading and spelling abilities in children who were extremely low birthweight. *Journal of the International Neuropsychological Society*, *9*(03), 440-449.

Edwards, V. T., Giaschi, D. E., Dougherty, R. F., Edgell, D., Bjornson, B. H., Lyons, C., et al. (2004). Psychophysical indexes of temporal processing abnormalities in children with developmental dyslexia. *Developmental Neuropsychology, 25*, 321–354.

Ellemberg, D., Lewis, T. L., Dirks, M., Maurer, D., Ledgeway, T., Guillemot, J. P., & Lepore, F. (2004). Putting order into the development of sensitivity to global motion. Vision research, 44(20), 2403-2411.

Ellemberg, D., Lewis, T. L., Maurer, D., Brar, S., & Brent, H. P. (2002). Better perception of global motion after monocular than after binocular deprivation. *Vision Research,* 42, 169–179.

Fechner, G. T. (1860). *Elemente der Psychophysik*. English translation: Howes, D. H. & Boring, E. C. (eds) and Adler, H. E. (transl.), New York: Holt (Rinehart & Winston) (1966).

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in neurosciences*, *15*(1), 20-25.

Goodale, M. A., & Milner, A. D. (1995). The visual brain in action. *Oxford University Press*, *27*, 134.

Goodale, M. A., & Westwood, D. A. (2004). An evolving view of duplex vision: separate but interacting cortical pathways for perception and action. *Current opinion in neurobiology*, *14*(2), 203-211.

Grill-Spector, K., Golarai, G., & Gabrieli, J. (2008). Developmental neuroimaging of the human ventral visual cortex. *Trends in cognitive sciences*, *12*(4), 152-162.

Grinter, E. J., Maybery, M. T., & Badcock, D. R. (2010). Vision in developmental disorders: is there a dorsal stream deficit?. *Brain research bulletin*, *82*(3), 147-160.

Grinter, E. J., Maybery, M. T., Pellicano, E., Badcock, J. C., & Badcock, D. R. (2010). Perception of shapes targeting local and global processes in autism spectrum disorders. *Journal of Child Psychology and Psychiatry*, *51*(6), 717-724.

Gunn, A., Cory, E., Atkinson, J., Braddick, O., Wattam-Bell, J., Guzzetta, A., & Cioni, G. (2002). Dorsal and ventral stream sensitivity in normal development and hemiplegia. *Neuroreport*, *13*(6), 843-847.

Hadad, B. S., Maurer, D., & Lewis, T. L. (2011). Long trajectory for the development of sensitivity to global and biological motion. *Developmental Science, 14(6)*, 1330-1339.

Hadad, B., Schwartz, S., Maurer, D., & Lewis, T. L. (2015). Motion perception: a review of developmental changes and the role of early visual experience. *Frontiers in integrative neuroscience*, *9,* 1-18.

Halberda, J., & Feigenson, L. (2008). Developmental change in the acuity of the" Number Sense": The Approximate Number System in 3-, 4-, 5-, and 6-year-olds and adults. *Developmental psychology, 44*(5), 1457.

Hansen, P. C., Stein, J. F., Orde, S. R., Winter, J. L., & Talcott, J. B. (2001). Are dyslexics' visual deficits limited to measures of dorsal stream function?. *Neuroreport*, *12*(7), 1527-1530.

Harvey, L. O. (1986). Efficient estimation of sensory thresholds. Behavior Research Methods, *Instruments, & Computers, 18(6),* 623-632.

Hess, R. F., & Aaen-Stockdale, C. (2008). Global motion processing: The effect of spatial scale and eccentricity. *Journal of vision*, *8*(4):11, 1-11.

Hess, R. F., & Zaharia, A. G. (2010). Global motion processing: Invariance with mean luminance. *Journal of vision*, *10*(13):22, 1-10.

Hess, R. F., Hutchinson, C. V., Ledgeway, T., & Mansouri, B. (2007). Binocular influences on global motion processing in the human visual system. *Vision research*, *47*(12), 1682-1692.

Hood, B., Atkinson, J., Braddick, O., & Wattam-Bell, J. (1992). Orientation selectivity in infancy: Behavioural evidence for temporal sensitivity. *Perception*, *21*, 351–354

Howley, S. A., Prasad, S. E., Pender, N. P., & Murphy, K. C. (2012). Relationship between reaction time, fine motor control, and visual–spatial perception on vigilance and visual-motor tasks in 22q11. 2 Deletion Syndrome. *Research in developmental disabilities*, *33*(5), 1495-1502.

Jakobson, L. S., Frisk, V., Knight, R. M., Downie, A. L., & Whyte, H. (2001). The relationship between periventricular brain injury and deficits in visual processing among extremely-low-birthweight (< 1000 g) children. *Journal of Pediatric Psychology*, *26*(8), 503-512.

Johnston, R., Pitchford, N. J., Roach, N. W., & Ledgeway, T. (2016a). Why is the processing of global motion impaired in adults with developmental dyslexia? *Brain and Cognition, 108*, 20‑31.

Johnston, R., Pitchford, N. J., Roach, N. W., & Ledgeway, T. (2016b). Motion-based segmentation is impaired in adults with developmental dyslexia *Perception*, *45*, 184-190.

Kaplan, E. (2004). The M, P, and K pathways of the primate visual system. *The visual neurosciences*, *1*, 481-493.

Keizer, A. W., Colzato, L. S., & Hommel, B. (2008). Integrating faces, houses, motion, and action: Spontaneous binding across ventral and dorsal processing streams. *Acta Psychologica*, *127*(1), 177-185.

Kikinis, Z., Makris, N., Finn, C. T., Bouix, S., Lucia, D., Coleman, M. J., & Kubicki, M. (2013). Genetic contributions to changes of fiber tracts of ventral visual stream in 22q11. 2 deletion syndrome. *Brain imaging and behavior*, *7*(3), 316-325.

Kobrynski, L. J., & Sullivan, K. E. (2007). Velocardiofacial syndrome, DiGeorge syndrome: the chromosome 22q11. 2 deletion syndromes. *The Lancet*, *370*(9596), 1443-1452.

Lacouture, Y., & Cousineau, D. (2008). How to use MATLAB to fit the ex-Gaussian and other probability functions to a distribution of response times. *Tutorials in Quantitative Methods for Psychology*, 4(1), 35-45.

Landolt, E. (1905). I Die Vereinheitlichung der Bestimmung der Sehschärfe. *Ophthalmologica, 13*(6), 519-541.

Laycock, R., Crewther, S. G., & Crewther, D. P. (2007). A role for the 'magnocellular advantage' in visual impairments in neurodevelopmental and psychiatric disorders. *Neuroscience & Biobehavioral Reviews*, *31*(3), 363-376.

Lebel, C., Walker, L., Leemans, A., Phillips, L., & Beaulieu, C. (2008). Microstructural maturation of the human brain from childhood to adulthood. *Neuroimage*, *40*(3), 1044-1055.

Levitt, H. (1970). Transformed up-down methods in psychoacoustics. *Journal of the Acoustical Society of America, 33*,467-476.

Levy, T., Walsh, V., & Lavidor, M. (2010). Dorsal stream modulation of visual word recognition in skilled readers. *Vision research*, *50*(9), 883-888.

Lewis, T. L., Ellemberg, D., Maurer, D., Wilkinson, F., Wilson, H. R., Dirks, M., & Brent, H. P. (2002). Sensitivity to global form in glass patterns after early visual deprivation in humans. *Vision research*, 42(8), 939-948.

Livingstone, M. S., & Hubel, D. H. (1987). Psychophysical evidence for separate channels for the perception of form, color, movement, and depth. *Journal of Neuroscience*, *7*(11), 3416-3468.

Losito, N., Tressoldi, P. E., & Cornoldi, C. Punti z o percentili? Sillabe/secondo, tempo complessivo o tempo/sillaba? Come valutare la rapidità nelle prove di lettura. *Dislessia, 11*(3), 295-311.

Lu, Z. L., & Sperling, G. (2001). Three-systems theory of human visual motion perception: review and update. *Journal of the Optical Society of America A*, *18*(9), 2331-2370.

Manning, C., Dakin, S. C., Tibber, M. S., & Pellicano, E. (2014). Averaging, not internal noise, limits the development of coherent motion processing. *Developmental cognitive neuroscience*, *10*, 44-56.

Martínez, A., Hillyard, S. A., Dias, E. C., Hagler, D. J., Butler, P. D., Guilfoyle, D. N., & Javitt, D. C. (2008). Magnocellular pathway impairment in schizophrenia: evidence from functional magnetic resonance imaging. *Journal of Neuroscience*, *28*(30), 7492-7500.

Maunsell, J. H. (1987). *Physiological evidence for two visual subsystems*. In *Matters of intelligence* (pp. 59-87). Netherlands: Springer Press.

Maunsell, J. H. R., Nealey, T. A., & DePriest, D. D. (1990). Magnocellular and parvocellular contributions to responses in the middle temporal visual area (MT) of the macaque monkey. *Journal of Neuroscience, 10*, 3323–3334.

Maunsell, J. H., & Newsome, W. T. (1987). Visual processing in monkey extrastriate cortex. *Annual review of neuroscience*, *10*(1), 363-401.

Maunsell, J. H., Ghose, G. M., Assad, J. A., McAdams, C. J., Boudreau, C. E., & Noerager, B. D. (1999). Visual response latencies of magnocellular and parvocellular LGN neurons in macaque monkeys. *Visual neuroscience*, *16*(01), 1-14.

Melnick, M. D., Harrison, B. R., Park, S., Bennetto, L., & Tadin, D. (2013). A Strong Interactive Link between Sensory Discriminations and Intelligence. *Current Biology, 23(11)*, 1013–1017.

Menghini, D., Finzi, A., Benassi, M., Bolzani, R., Facoetti, A., Giovagnoli, S., & Vicari, S. (2010). Different underlying neurocognitive deficits in developmental dyslexia: a comparative study. *Neuropsychologia, 48*(4), 863-872.

Merigan, W. H., & Maunsell, J. H. (1993). How parallel are the primate visual pathways?. *Annual review of neuroscience*, *16*(1), 369-402.

Milne, E., Swettenham, J., Hansen, P., Campbell, R., JeVries, H., & Plaisted, K. (2002). High motion coherence thresholds in children with autism. *Journal of Child Psychology and Psychiatry, 43*, 255–263.

Mishkin, M., Ungerleider, L. G., & Macko, K. A. (1983). Object vision and spatial vision: two cortical pathways. *Trends in neurosciences*, *6*, 414-417.

Moivre, A. de (1733). *Approximatio ad Summam Ferminorum Binomii in Seriem expansi*, Supplementum II to Miscellanae. Analytica, 1–7.

Moivre, A. de (1738). *The doctrine of chances*. London: Fank Cass & Co (Reprint 1967).

Myung, I. J. (2003). Tutorial on maximum likelihood estimation. *Journal of mathematical Psychology*, 47(1), 90-100.

Narasimhan, S., & Giaschi, D. (2012). The effect of dot speed and density on the development of global motion perception. *Vision research*, 62, 102-107.

Neri P., Morrone M.C., & Burr D. (1998). Seeing biological motion. Nature, *395*, 894–96.

Newsome, W. T., & Pare, E. B. (1988). A selective impairment of motion perception following lesions of the middle temporal visual area (MT). *Journal of Neuroscience*, *8*(6), 2201-2211.

Nishida, S. Y. (2011). Advancement of motion psychophysics: Review 2001–2010. *Journal of Vision*, *11*(5), 11.

Noonan, J. A. (1994). Noonan syndrome an update and review for the primary pediatrician. *Clinical pediatrics*, *33*(9), 548-555.

Nothdurft, H. C. (1993). The role of features in preattentive vision: Comparison of orientation, motion and color cues. *Vision Research*, *33*, 1937–1958.

O'Keefe, L. P., & Movshon, A. J. (1998). Processing of first and second-order motion signals by neurons in area MT of the macaque monkey. *Visual Neuroscience*, 15, 305–317.

O'Brien, J., Spencer, J., Atkinson, J., Braddick, O., & Wattam-Bell, J. (2002). Form and motion coherence processing in dyspraxia: evidence of a global spatial processing deficit. *Neuroreport*, *13*(11), 1399-1402.

Orban, G. A. (2008). Higher order visual processing in macaque extrastriate cortex. *Physiological Review, 88*, 59–89.

Ostwald, D., Lam, J. M., Li, S., & Kourtzi, Z. (2008). Neural coding of global form in the human visual cortex. *Journal of Neurophysiology*, *99*(5), 2456-2469.

Pammer, K., & Wheatley, C. (2001). Isolating the M(y)-cell response in dyslexia using the spatial frequency doubling illusion. *Vision Research, 41*, 2139–2147.

Parrish, E. E., Giaschi, D. E., Boden, C., & Dougherty, R. (2005). The maturation of form and motion perception in school age children. *Vision research*, *45*(7), 827-837.

Pilly, P. K., & Seitz, A. R. (2009). What a difference a parameter makes: A psychophysical comparison of random dot motion algorithms. *Vision research*, *49*(13), 1599-1612.

Pinto J. & Shiffrar M. (1999). Subconfigurations of the human form in the perception of biological motion displays. *Acta Psychologica, 102*, 293–318.

Poom L., & Olsson H. (2002). Are mechanisms for perception of biological motion different from mechanisms for perception of nonbiological motion? *Perception of Motion Skills, 95*, 1301–10.

Purghè F. (1997), *Metodi di psicofisica e scaling unidimensionale.* Torino: Bollati Boringhieri.

Raven, J. C. (1992). *CPM: Coloured progressive matrices: serie A-AB-B*. OS Organizzazioni Speciali.

Raven, J., Raven, J., Court J. (1962). *Coloured progressive matrices*, Psychologists Press, Oxford, England.

Ross, J., Badcock, D. R., & Hayes, A. (2000). Coherent global motion in the absence of coherent velocity signals. *Current Biology*, *10*(11), 679-682.

Saalmann, Y. B., Pigarev, I. N., & Vidyasagar, T. R. (2007). Neural mechanisms of visual attention: how top-down feedback highlights relevant locations. *Science*, *316*(5831), 1612-1615.

Saffell, T., & Matthews, N. (2003). Task-specific perceptual learning on speed and direction discrimination. *Vision Research*, *43*, 1365–1374.

Schenk, T., & Zihl, J. (1997). Visual motion perception after brain damage: I. Deficits in global motion perception. *Neuropsychologia*, *35*(9), 1289-1297.

Schenk, T., Ellison, A., Rice, N., & Milner, A. D. (2005). The role of V5/MT+ in the control of catching movements: an rTMS study. *Neuropsychologia*, *43*(2), 189-198.

Schulte-Korne, G., Bartling, J., Deimel, W., & Remschmidt, H. (2004). Visual evoked potential elicited by coherently moving dots in dyslexic children. *Neuroscience Letters, 357*, 207–210.

Shprintzen, R. J. (2000). Velo- cardio- facial syndrome: A distinctive behavioral phenotype. *Mental retardation and developmental disabilities research reviews*, *6*(2), 142-147.

Simic, N., & Rovet, J. (2016). Dorsal and ventral visual streams: Typical and atypical development. *Child Neuropsychology*, 1-14.

Sincich, L. C., & Horton, J. C. (2002). Divided by cytochrome oxidase: A map of the projections from V1 to V2 in macaques. *Science, 295*, 1734–1737.

Skoczenski, A. M., & Norcia, A. M. (2002). Late maturation of visual hyperacuity. *Psychological Science*, *13*, 537–541.

Skottun, B. C., & Skoyles, J. R. (2006). Is coherent motion an appropriate test for magnocellular sensitivity?. *Brain and cognition*, *61*(2), 172-180.

Skottun, B. C., & Skoyles, J. R. (2008). Temporal frequency and the magnocellular and parvocellular systems. *Neuro-Ophthalmology*, *32*(2), 43-48.

Skottun, B. C., & Skoyles, J. R. (2011). On identifying magnocellular and parvocellular responses on the basis of contrast-response functions. *Schizophrenia bulletin*, *37*(1), 23-26.

Slater, A., Morrison, V., & Rose, D. (1988). Orientation discrimination and cortical function in the human newborn. *Perception*, *17*, 597–602.

Smith, A. T., Snowden, R. J., & Milne, A. B. (1994). Is global motion really based on spatial integration of local motion signals? *Vision Research*, 34, 2425–2430

Snowden, R. J., & Kavanagh, E. (2006). Motion perception in the ageing visual system: Minimum motion, motion coherence, and speed discrimination thresholds. *Perception*, *35*(1), 9-24.

Stein, J. (2003). Visual motion sensitivity and reading. *Neuropsychologia*, *41*(13), 1785-1793.

Strasburger, H. (2001). Converting between measures of slope of the psychometric function. *Perception & Psychophysics, 63(8)*, 1348-1355.

Swillen, A., Vandeputte, L., Cracco, J., Maes, B., Ghesquière, P., Devriendt, K., & Fryns, J. P. (1999). Neuropsychological, learning and psychosocial profile of primary school aged children with the velo-cardio-facial syndrome (22q11 deletion): evidence for a nonverbal learning disability?. *Child Neuropsychology*, *5*(4), 230-241.

Talcott, J. B., Hansen, P. C., Assuko, E. L., & Stein, J. F. (2000). Visual motion sensitivity in dyslexia: Evidence for temporal and energy integration deficits. *Neuropsychologia, 38*, 935–943.

Tartaglia, M., & Gelb, B. D. (2010). Disorders of dysregulated signal traffic through the RAS-MAPK pathway: phenotypic spectrum and molecular mechanisms. *Annals of the New York Academy of Sciences*, *1214*(1), 99-121.

Thornton I.M., Pinto J., & Shiffrar M. (1998). The visual perception of human locomotion. *Cognition Neuropsychological, 15*, 535–52.

Torgerson, W. S. (1958). *Theory and methods of scaling*. NewYork: Wiley.

Treisman, M., & Watts, T. R. (1966). Relation between signal detectability theory and the traditional procedures for measuring sensory thresholds: Estimating d'from results given by the method of constant stimuli. *Psychological Bulletin, 66(6)*, 438.

Treutwein, B. (1995). Adaptive psychophysical procedures. *Vision research, 35*(17), 2503-2522.

Van Zandt, T., & Townsend, J. T. (2014). Designs for and analyses of response time experiments. *The Oxford Handbook of Quantitative Methods: Foundations*, Oxford Library of Psychology: Oxford.

Vicari, S., Mantovan, M., Addona, F., Costanzo, F., Verucci, L., & Menghini, D. (2012). Neuropsychological profile of Italian children and adolescents with 22q11. 2 deletion syndrome with and without intellectual disability. *Behavior genetics*, *42*(2), 287-298.

Warrington, E. K., & James, M. (1988). Visual apperceptive agnosia: A clinico-anatomical study of three cases. *Cortex*, *24*(1), 13-32.

Warrington, E. K., & Taylor, A. M. (1973). The contribution of the right parietal lobe to object recognition. *Cortex*, *9*(2), 152-164.

Watamanuik, S. N. J., & Sekuler, R. (1992). Temporal and spatial integration in dynamic random-dot stimuli. *Vision Research*, 32, 2341–2347.

Wattam-Bell, J., Birtles, D., Nyström, P., von Hofsten, C., Rosander, K., Anker, S., & Braddick, O. (2010). Reorganization of global form and motion processing during human visual development. *Current Biology*, *20*(5), 411-415.

Wichmann, F. A., & Hill, N. J. (2001). The psychometric function: I. Fitting, sampling, and goodness of fit. *Perception & psychophysics, 63(8),* 1293-1313.

Wilson, D. I., Burn, J., Scambler, P., & Goodship, J. (1993). DiGeorge syndrome: part of CATCH 22. *Journal of Medical Genetics*, *30*(10), 852-856.

Wilson, H. R., & Wilkinson, F. (1998). Detection of global structure in Glass patterns: implications for form vision. *Vision research*, *38*(19), 2933-2947.

Wixted J. (2004). *Stevens' Handbook of Experimental Psychology, Volume 4: Methodology in Experimental Psychology*. John Wiley & Sons: Hoboken.

Yabuta, N. H., Sawatari, A., & Callaway, E. M. (2001). Two functional channels from primary visual cortex to dorsal visual cortical areas. *Science, 292*, 297–300.

Zeki, S. M. (1978). Functional specialisation in the visual cortex of the rhesus monkey. *Nature*, *274*(5670), 423-428.

Zeki, S., & Shipp, S. (1988). The functional logic of cortical connections. *Nature, 335,* 311–317.