Age and sex differences in proprioception based on fine motor behaviour

Liudmila Liutsko

PhD. Dissertation

AGE AND SEX DIFFERENCES IN PROPRIOCEPTION BASED ON FINE MOTOR BEHAVIOUR

Program: Personality Assessment and Behaviour

Author: Liudmila Liutsko

Thesis director: Dr Josep María Tous Ral

Department of Personality, Assessment and Treatment

Faculty of Psychology

University of Barcelona

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Dedication

To my family of all generations (past and future):

without you I could not exist, or continue to exist…

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The list of persons whom I like to say thanks is not limited to those I have already mentioned. I would like also mention my gratitude to Tom Molloy for his help and correction of English. My final but not least acknowledgements belong to University of Barcelona, whose financial support made my study and work at the Mira y Lopez Laboratory a reality.

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RESUM (Català)

La tesi doctoral *Age and sex differences in proprioception based on fine motor behaviour* contribueix tant a la sinterització del material bibliogràfic, revisat de fonts originals, escrit en diferents idiomes (a vegades desconegudes en la comunitat científica a nivell internacional, ja que no van ser publicades en anglès) com a la investigació científica amb els resultats de les investigacions experimentals, dutes a terme al Laboratori Mira i López de la Universitat de Barcelona, en l'estudi empíric de les diferències individuals en la propiocepció, basades en el comportament motor fi. L'objectiu principal teòric d'aquest treball és mostrar la importància de la propiocepció, com a base de les diferències individuals, per a la salut humana i la qualitat de vida. La major part del treball experimental es basa en la constatació de les diferències individuals en la motricitat fina propioceptiva relacionades amb l'edat i el sexe que permet analitzar i entendre aquestes diferències en el comportament humà. Quan la autocorrecció de la conducta no és possible (la persona no veu els traços dels seus moviments en la part propioceptiva del test), l'expressió grafomotora reflecteix les qualitats intrínseques de cada persona, basades en factors biològics, o endògens, específiques del sistema nerviós i la conducta adaptativa, apreses en les seves pròpies experiències amb les interaccions ambientals.

Els treballs experimentals s'han realitzat amb l'ús del Diagnòstic Propioceptiu de Temperament i el Caràcter o DP-TC, en abreviatura espanyola (Tous, Muiños, Tous, O. i Tous, R., 2012), que és el resultat més recent de molts anys de treball dins la línia de la tradició del Psicodiagnòstic Miokinético (PMK) de Mira i López. El DP-TC és el resultat de la digitalització i validació estadística dels subtests corresponents als lineogramas i les paral · leles del PMK. Mitjançant aquest programa especial, el comportament grafomotor fi (precisió i velocitat) pot ser registrat i mesurat, ja que permet transformar les mesures en mil·límetres, del sistema mètric, a píxels. Per a l'estudi de les diferències individuals es van utilitzar diferents tipus de moviment: frontal, transversal i sagital, amb les dues mans per separat i dues condicions sensorials: propioceptiva-visual (PV), on es pot observar la funció d'integració de les dues condicions sensorials i només propioceptiva (P) on es pot observar la informació propioceptiva en la conducta motora fina. Els estudis experimentals van ser sobre les diferències individuals en el sexe i l'edat, encara que es dóna també, al final d'aquesta tesi, un breu resum d'altres estudis -alguns transculturals- que mostren la relació de la informació propioceptiva amb l'emoció i la cognició.

Les principals contribucions d'aquest treball són els següents:

- Treball bibliogràfic comentat sobre el tema de la propiocepció i les diferències individuals i la importància per a la salut humana i la qualitat de vida que es realitza per primera vegada i es pot utilitzar per a una comprensió més àmplia a l'hora de realitzar futures investigacions i aplicacions (treballs terapèutics i educatius més eficaços). La informació recollida es pot utilitzar i adaptar per formar part del programa formatiu, especialment en les facultats de psicologia, pedagogia i neurologia.
- S'ha realitzat una breu descripció de la conducta motora fina en diferents cultures: Àrab, (que té l'hàbit d'escriure en una altra direcció que a Occident) i Bielorussa (per a aquests últims, alguns resultats es donen amb relació als paràmetres físics i verbals) que es representa a la part inicial del tesis.
- L'estudi de les diferències propioceptives dependents de l'edat, basades en la conducta motora fina, en 196 participants 12-95 anys d'edat, que va permetre constatar que la funció polinòmica era la millor opció per a la descripció de l'evolució de la reproducció de la longitud de línia de traços en els moviments frontals i transversals.
- Es va constatar que la funció de propiocepció era la primera que empitjorava en la precisió amb l'augment de l'edat abans de l'empitjorament de la funció integradora realitzada per les dues entrades sensorials (propioceptiva i visual);
- Es posen de manifest les edats crucials per als canvis propioceptius dependents de l'edat; els resultats per primera vegada donen el suport experimental de l'edat de la crisi de l'edat mitjana (approx. 40 anys).
- S'han analitzat i discutit les diferències de sexe i la interacció sexe per edat;
- S'ha fet anàlisi correlacional entre precisió motora fina i la velocitat en dues condicions sensorials del test.
- Es dona en la part final de la tesi la descripció de les aplicacions dels resultats de la tesi i els interessos potencials de la investigació futura en l'àrea de la propiocepció i les diferències individuals.

ABSTRACT (English)

The PhD thesis *Age and sex differences in proprioception based on fine motor behaviour* contributes to a synthesis of the bibliographic material reviewed from original sources written in various languages (and thus sometimes unknown in the scientific community at international level, since they were not published in English) and to scientific research by findings and results from experimental work carried out at the Mira y López Laboratory of the University of Barcelona on topics related to individual differences in proprioception based on fine motor behaviour. The main aim of this work is to show the importance of proprioceptive sense, as a basis of individual differences, for human health and life quality. Most of the experimental work is related to sex and age-dependent differences in human fine behaviour, thus allowing analysis and understanding of those differences. When self-correction of behaviour is not possible (the person does not see the feedback of his/her movements), the expression reflects the intrinsic qualities of each person based both on biological or endogenous factors or ones specific to the nervous system and adaptive behaviour learnt during his/her own experience with environmental interactions.

Experimental work was carried out with use of the latest proprioceptive diagnostics which was a result of many years of work within the Mira y Lopez myokinetic psychodiagnosis (MKP) tradition, Proprioceptive Diagnostics of Temperament and Character or DP-TC in Spanish abbreviation (Tous, Muiños, Tous, O. i Tous, R., 2012). DP-TC was a result of digitization and statistical validation of MKP lineograms' and parallels` parts. Thus, due to this special software, graphomotor fine behaviour (precision and speed) can be registered and measured and converted to the metric system: from pixels to millimetres. For the study of individual differences, various movement types were used: frontal, transversal and sagittal, both hands and two sensory conditions: proprioceptive-visual (PV), where the integration function of both sensory conditions can be observed, and proprioceptive-only (P). The experimental studies were cross-sectional and analysed for sex- and age-dependent individual differences mainly, although a brief résumé of other studies was included, showing the relationship between proprioceptive information feedback and both emotion and cognition, at the end of this thesis.

The major contributions of this work are the following:

- synthetic bibliographical work on the topic of proprioception and individual differences and importance for human health and quality of life, which is conducted for the first time and can be used for wider understanding in order to carry out future research and application (more effective therapeutic and educational work), and can be used and adapted to form part of a program, especially for psychological, pedagogical and neurological faculties;
- brief description of fine motor behaviour in different cultures: Arabic (in which the custom is to write in a different direction to Western people); and Belarus (for the latter some results are given, together with relationships to verbal and other physical parameters) is represented in the initial part of the thesis;
- an age-dependent proprioceptive differences study based on fine motor behaviour in 196 participants from 12 to 95 years old, in which the polynomial function was of the best fit for size (line length tracings) in frontal and transversal movements;
- it was shown that proprioception function was the first to deteriorate in precision with increasing age value if compared to the integrative function of both sensory inputs (proprioceptive and visual);
- the crucial ages for age-dependent changes were shown for the first time; these results give the first experimental support for the age of the mid-life crisis (approx. 40 years);
- sex-dependent differences and sex*age-dependent differences were analysed and discussed also;
- a correlational analysis was performed between precision and fine motor speed in two sensory conditions of the test;
- practical applications of study results together with the future potential research interests in the area of proprioception and individual differences are given in the final part of the work.

RESUMEN (Spanish)

La tesis doctoral *Age and sex differences in proprioception based on fine motor behaviour* contribuye tanto a la sintonización del material bibliográfico, revisado de fuentes originales, escrito en diferentes idiomas (a veces desconocidos en la comunidad científica a nivel internacional, ya que no fueron publicadas en inglés) como a la investigación científica con los resultados de las investigaciones experimentales, llevadas a cabo en el Laboratorio Mira y López de la Universidad de Barcelona, en el estudio empírico de las diferencias individuales en la propiocepción, basadas en el comportamiento motor fino. El objetivo principal teórico de este trabajo es mostrar la importancia de la propiocepción, como base de las diferencias individuales, para la salud humana y la calidad de vida. La mayor parte del trabajo experimental se basa en la constatación de las diferencias individuales en la motricidad fina propioceptiva relacionadas con el sexo y la edad que permite analizar y entender esas diferencias en el comportamiento humano. Cuando la autocorrección de la conducta no es posible (la persona no ve los trazos de sus movimientos en la parte propioceptiva del test), la expresión grafomotora refleja las cualidades intrínsecas de cada persona, basadas en factores biológicos, o endógenos, específicos del sistema nervioso y la conducta adaptativa, aprendidas en sus propias experiencias con las interacciones ambientales.

Los trabajos experimentales se han realizado con el uso del Diagnóstico Propioceptivo de Temperamento y el Carácter o DP-TC, en abreviatura española (Tous, Muiños, Tous, O. y Tous, R., 2012), que es el resultado más reciente de muchos años de trabajo dentro de la línea de la tradición del Psicodiagnóstico Miokinético (PMK) de Mira y López. El DP-TC es el resultado de la digitalización y validación estadística de los subtests correspondientes a los lineogramas y las paralelas del PMK. Mediante este software especial, el comportamiento grafomotor fino (precisión y velocidad) puede ser registrado y medido; ya que permite transformar las medidas en milímetros, del sistema métrico, a píxeles. Para el estudio de las diferencias individuales se utilizaron diferentes tipos de movimiento: frontal, transversal y sagital, con ambas manos por separado y dos condiciones sensoriales: propioceptiva-visual (PV), donde se puede observar la función de integración de ambas condiciones sensoriales y solamente propioceptiva (P) donde se puede observar la información propioceptiva en la conducta motora fina. Los estudios experimentales fueron sobre las diferencias individuales en el sexo y la edad, aunque se da también, al final de esta tesis, un breve resumen de otros estudios -algunos transculturales- que muestran la relación de la información propioceptiva con la emoción y la cognición. Las principales contribuciones de este trabajo son los siguientes:

- Trabajo bibliográfico comentado sobre el tema de la propiocepción y las diferencias individuales y la importancia para la salud humana y la calidad de vida de estos estudios que se realiza por primera vez y se puede utilizar para una comprensión más amplia a la hora de realizar futuras investigaciones y aplicaciones (trabajos terapéuticos y educativos más eficaces) que se puede utilizar y adaptar para formar de un parte programa formativo, especialmente en las facultades de psicología, pedagogía y neurología.

- Se ha realizado una breve descripción de la conducta motora fina en diferentes culturas: Árabe, (que tiene el hábito de escribir en otra dirección que en Occidente) y Bielorrusa (para estos últimos, algunos resultados se dan con relación a los parámetros físicos y verbales) que se representa en la parte inicial de la tesis.

- El estudio de las diferencias propioceptivas dependientes de la edad, basadas en la conducta motora fina, en 196 participantes 12 a 95 años de edad, que permitió constatar que la función polinómica era la mejor opción para la descripción de la evolución de la reproducción del tamaño (longitud de línea de trazos) en los movimientos frontales y transversales.

- Se constató que la función de propiocepción la primera que empeora en la precisión con el aumento de la edad antes del empeoramiento de la función integradora realizada por las dos entradas sensoriales (propioceptiva y visual);

- Se ponen de manifiesto las edades cruciales para los cambios propioceptivos dependientes de la edad; por la primera vez experimentalmente se justifican las fases de desarrollo y de la crisis de edad media en la base de propiocepción.

- Se han analizado y discutido las diferencias de sexo y la interacción sexo por edad.

- Las aplicaciones prácticas de los resultados derivados de la tesis y los intereses potenciales de la investigación futura en el área de la propiocepción y las diferencias individuales están representados en la parte final del manuscrito.

РЕЗЮМЕ (Русский)

Кандидатская диссертация на тему «*Возрастные и половые различия в проприоцепции на основе исследования тонкой моторики»* даёт детальный анализ библиографического материала, собранного из первоисточников, написанных на различных языках (иногда неизвестных в научном международном сообществе, так как не были опубликованы на английском языке); а также научных исследований, выводов и результатов экспериментальных работ, выполненныхв Лаборатории Мира Лопес Барселонского Университета Барселоны на темы, связанные с индивидуальными различиями в проприоцепции на основе проявлений тонкой моторики. Основной целью данной работы является показать важность изучения проприоцептивного чувства в исследовании индивидуальных различий, так и в связи с исследованием здоровья человека и качества жизни. Большинство экспериментальных работ, представленных в диссертации, связаны с половыми и возрастными индивидуальными различиями в проявлении тонкой моторики; таким образом, результаты этих работ позволяют проанализировать и понять эти индивидуальные различия. В проприоцептивной части теста самостоятельная коррекция моторного акта на основе зрительного контроля невозможна. В связи с этим характеристика этих движений отражает индивидуальные качества каждого человека, формирующихся как на основе биологических (эндогенных факторов или специфических свойств нервной системы), так и на базе адаптивно усвоенного поведения (его собственного опыта, полученного в результате взаимодействия с окружающей средой).

Экспериментальная работа проводилась с использованием новейшей проприоцептивной диагностики, которая является результатом многих лет работы в традициях миокинетической психодиагностики (MKP) Мира и Лопеса, Проприоцептивная Диагностика Темперамента и Характера или DP-TC в испанской аббревиатуре (Tous, Muiños, Tous, O.,Tous, R., 2012). DP-TC возник как результат применения новейших технологий (компьютеров и тактильных экранов), а также статистической проверки MKP, линеограмм и параллелей. Таким образом, с помощью специального программного обеспечения, мелкое графомоторное поведение (точность и скорость) может быть зарегистрировано, измерено и преобразовано в метрическую систему: с пикселей в миллиметры. Для

изучения индивидуальных различий были использованы различные типы движения: фронтальный, трансверсальный и сагиттальной, обе руки и два сенсорных условия: проприоцептивно-визуальное (PV), с интегральной опорой на проприоцептивную и сенсорную афферентацию, и с опорой только на проприоцептивную афферентацию (P).

Экспериментальные исследования были трансверсального типа и анализировали главным образом половые и возрастные индивидуальные различия. Также в диссертации приводится обзор данных других исследований, показывающих взаимосвязь показателей проприоцепции с эмоциями и познавательной сферой (памятью).

Основные результаты этой работы:

- анализ литературы по теме «Проприоцепция и индивидуальные различия, и ее значение для здоровья человека и качества жизни», который характеризуется теоретической новизной и большой практической значимостью (для более эффективных терапевтической и воспитательной работы), данный анализ литературы может быть с успехом использован при разработке образовательных программ, особенно для психологических, педагогических и неврологических факультетов;

- краткое описание проявлений тонкой моторики в разных культурах: арабской (где практикуется письмо справа налево, в отличие от письма в западной культуре) и Беларуси (для последних некоторые результаты приведены вместе с корреляционным анализом взаимосвязи проприоцептивного метода с вербальными методиками и другими физическими параметрами) представлено в начальной части диссертации;

- исследование возрастных различий в проприоцептивной функции на основе проявлений тонкой моторики, в котором приняли участие 196 испытуемых в возрасте от 12 до 95 лет, результаты которого показали, что полиномиальная функция наилучшим образом подходила для длины линий (трассировки длины линии) во фронтальных и трансверсальных движениях;

- было показано, что проприоцептивная функция начинала ухудшаться первой с увеличением возраста по сравнению с интегративной функцией (проприоцептивно-визуальной);

- критические точки (точки перегиба) возраста для возрастных изменений были показаны впервые экспериментально, что также в некоторой степени соответствует обозначенному возрасту кризиса середины жизни (около 40 лет) и другим фазам развития;

- обсуждены и проанализированы половые и поло-возрастные различия тонкой моторики;

- предоставлен корреляционный анализ зависимости точности тонкой моторики и скорости выполнения задания в двух сенсорных условиях теста;

- практические применения результатов и перспективы дальнейших исследований в области проприоцепции и индивидуальных различий рассмотрены в заключительной части диссертации.

KEY WORDS

Paraules claus: propiocepció, Laboratori Mira y Lopez, Diagnòstic Propioceptiu de Temperament i Carácter, diferencies individuals, control de la motoricitat fina, psicología del desenvolupament, crisi de mitja-vida

Key words: proprioception, Mira y Lopez Laboratory, Proprioceptive Diagnosis of Temperament and Character, individual differences, fine motor control, developmental psychology, mid-life crisis

Palabras claves: propiocepción, Mira y López Laboratorio, Diagnóstico Propioceptivo de Temperamento y Carácter, diferencias individuales, control de la motricidad fina, la psicología del desarrollo, crisis de la mediana edad

Ключевые слова: проприоцепция, лаборатория Мира и Лопеса, Проприоцептивная Диагностика Темперамента и Характера, индивидуальные различия, контроль тонкой моторики, психологии развития, кризис среднего возраста

CHAPTER 1. INTRODUCTION

The most important sides of things are hidden from
us due to their simplicity and our habituation to them…
Vittgenshtein (cited in Sacks, 1985)

[We need] *a new sort of neurology, a 'personalistic',*
or (as Luria liked to call it) a 'romantic', science;
for the physical foundations of the persona, the self.
(Sacks, 1985).

1.1. History and definitions. Proprioception as a basis for individual differences

Proprioception, from "*proprio*" and "*ception*", means perception of our-selves, or more exactly, perception of the relative positions of the parts of our body: "the ability of an individual to determine body segment positions and movements in space, and is based on sensory signals provided to the brain from muscle, joint and skin receptors" (Goble, 2010). Julius Caesar described it as a "sense of locomotion" in 1557; Charles Bell mentioned it as a "muscle sense" in 1826; and later Henry Charlton Bastian substituted it for "kinaesthesia", since the afferent information was coming not only from muscles, but also from tendons, joints and skin (*Proprioception*[a], 2007). Sensory inputs from proprioceptors (located in muscles, tendons and joints) are integrated with information from other receptors (such as vestibular apparatus) to provide an awareness of the relative body part position or movements. However, there are two concepts that are closely related to balance and proprioception – equilibrioception and spacioception. Equilibrioception is a sense of balance, perceived by the position of fluids in the inner ear. However, some definitions of proprioception include perception of balance with awareness of equilibrium involving the perception of gravity (*Proprioception*[a], 2007). Spacioception, which forms a basis of movement precision, is based on both exteroceptive and interoceptive senses such as sight, touch, hearing, balance and proprioceptive information. Most important for movement coordination are the visual, proprioceptive and balance feedbacks and their compensative integrative function. Proprioception itself, named as a sixth sense after Dennis (2006), is information about the position of and changes being undergone by our body, without using the other five senses.

The term “proprioception” as such was introduced by Sherrington (1906) although we had always had this basic feeling of ourselves. Proprioception, the perception of body awareness, is a sense that people are frequently not aware of, but rely upon enormously. More easily demonstrated than explained, proprioception is the "unconscious" awareness of where the various regions of the body are located at any given time. For example, with closed eyes, we can say where our hands or legs are at this moment. Without proprioception we could not bring a spoon with soup in it to the mouth, ride a bicycle or change the gears of a car without looking at our hands or feet. Without this sense there would be no brilliant pianists or sportsmen, and we could not even write or walk without watching where we put our feet.

As far as awareness concerned, two types of proprioception are distinguished in humans:

1) *conscious proprioception,* which is communicated by the posterior column-medial lemniscuses pathway to the cerebellum; and
2) *unconscious proprioception,* which is communicated primarily via the dorsal spinocerebellar tract to the cerebellum. (*Proprioception*[c], 2009).

The cerebellum is largely responsible for coordination the unconscious aspects of proprioception (Fig. 1).

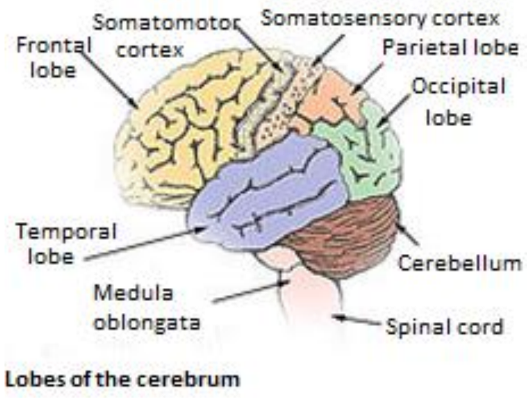


Figure 1.1.1. Cerebrum and its lobes. (Proprioception[a], 2007); quality of picture adapted by author.

In 1863, in the work "Refleksi golovnogo mozga" [In Russian, *Reflexes of brain*], the famous Russian physiologist Sechenov called proprioception a "dark muscle sense" (Sechenov, 2013, originally published 1863), and described the role of that muscle sense in the training of vision, hearing and other senses, especially in his work "Elements of thoughts" (Sechenov, 2013). He demonstrated that spatial vision is formed first of all with the help of proprioceptors of the eye muscles, and, secondly, due to multiple evaluation and combination of distance by eyes or legs. As for distance measurements, we still conserve in some countries "proprioceptive" (related to the length of body parts) units like "feet", "inch", or the old ones such as ell (originally a cubit, i.e., approximating to the length of a man's arm from the elbow to the tip of the middle finger, or about 18 inches), dactilus or digit, and palm in ancient Greece.

As in Sechenov thought, the muscle is not only analysing components of space, but also of time: "Near, far, height of subjects, their traces and velocities – all are the products of the muscle sense… The same muscle sense, being partial (fractioned) in periodical movements, becomes a partial measurement instrument of space and time" (Sechenov, 2013).

There are three types of muscular sense:

1) *Sense of position* – the capacity to feel at which angle every joint is, as well as overall body position and posture. The sense of position cannot be adapted.
2) *Sense of movement* – information about the direction and speed of joint movements. A person can perceive both active (induced by himself) and passive (externally induced) movements.
3) *Sense of force* – a capacity to evaluate the muscle force needed for movement or maintaining of the joint in a particular position (Schmidt, 1984; Proprioception[c], 2009).

Thus, due to proprioceptive sense, man can perceive position, movement and force.

Information from the proprioceptors passes through large nervous channels, and for this reason, has high speed (can reach 360 km/h) to reach the nucleus of the CNS, and through the thalamus, the cortex (parietal lobe), where the body scheme (see Figure 1.1.2 for homunculus representation) is created. A healthy person in conscious state can feel the position and movement of his limbs at the precision of 0.5 degree in angle changes in shoulder movement and estimate resistance to own force, in particular the weight of the things, with an error of 10% or less (Schmidt, 1984).

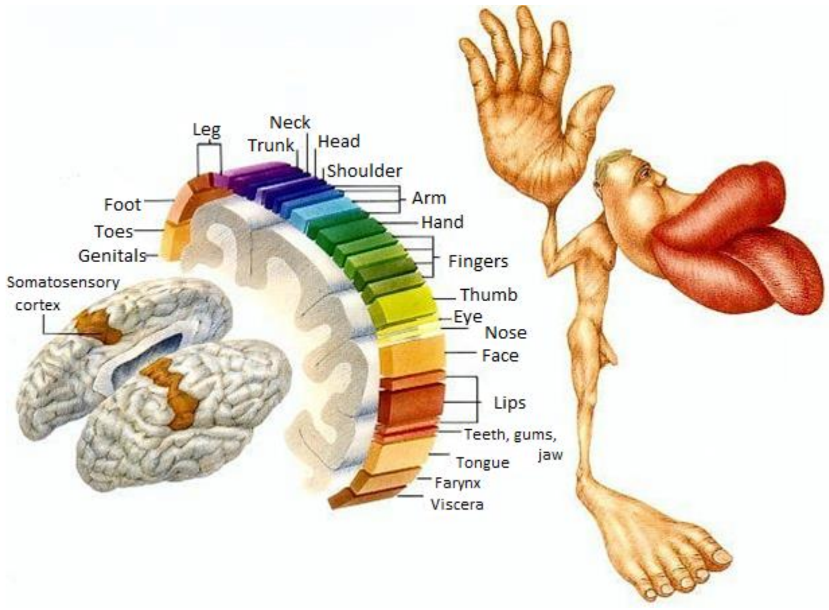


Figure 1.1.2. Illustrated Penfield homunculus map (Cicinelli, 2011) (used with permission), quality of picture adapted by author.

Proprioception is tested by Russian neurologists when they ask patients to touch thier nose with their finger or walk with eyes closed along a straight line drawn on the floor. It is also checked by American police officers by having suspect touch their nose by finger with eyes closed to see if there is a case of severe alcohol intoxication: people with normal proprioception make an error of no more than twenty millimetres.

When proprioception is altered, sensitive ataxia can take place, as in the clinical case described by Wingenshtein (Schmidt, 1984), when the patient after the operation had lost her proprioception and gradually forgot how to move or eat, and even stopped breathing. To return herself to life, she would compensate the proprioceptive loss by other senses, principally by vision, as in the Ian Waterman case (BBC movie, 1998, *The man who lost his body*). If proprioceptive impairment takes place, due to some part of the body being missing from one's mental self-image, we need to check it visually (to look down at our's limbs, for example) or by touch (to pinch ourselves to feel this part); however, under a complete loss of proprioception in all or a part of body, we simply cannot feel it and may guide ourselves only visually, as in the Ian Waterman case. In order to learn to walk again, he used his eyes and needed to look at his feet always while moving (BBC movie, 1998, *The man who lost his body*).

Small proprioceptive alterations are felt when one catches cold or is simply tired. Under vibration or other external/internal stimuli (real and virtual) proprioceptive changes can appear, such as the "Pinocchio effect" (Kilteni, Normand, Sanchez-Vives, Slater, 2012; Lackner, 1988; Pinocchio illusion, 2007) when body size perception is altered (perceived as too large or too small). To experience the "Pinocchio Illusion", you need to apply a vibrator to the biceps tendon while one holding your nose with the ipsilateral hand. Muscle stretching occurs due to stimulation of the muscle spindles by vibrator, creating a kinaesthetic illusion of the arm moving away from the face. Since the fingers are still holding the nose, this results in a perception that the nose is moving away from the face also, and thus enlarging. Similar effects (changes of body parts size) happen during epilepsy or migraine auras or during the changes in gravity when astronauts are passing the frontier of Earth's gravity, or in reactive airplane tests that take the ballistic curve of Kepler (when the weightlessness lasts between 20 to 60 seconds), as per Lebedev's self-observation (Leonov & Lebedev, 1965):

Due to motor noise and vibration, I guessed that the airplane was accelerating. After several seconds the overload had occurred… I felt like I was *falling down an abysm. This feeling, I estimated as lasting 1-2 seconds… Knowing very well theoretically about difficulties of weightlessness, I expected to spend it badly; however it was a contrary reaction. I felt delight that transformed later into euphoria… Then the overload started again. The state of weightlessness came suddenly and I flew up and then off in an indefinite direction. It was a moment of full disorientation in space. Later I came to recognize the situation. I saw the floor and walls of the room. The latter seemed to be enlarging. The illusion was like looking through inverted binoculars. When I looked at the floor, it was enlarging and shrinking like escaping and moving from me. At that moment I tried to grab for something. Though the objects seemed to me to be close, I could not reach them and that fact provoked the sharpest emotional excitation."*

Konstantin Tsiolkovsky suggested that in the condition of weightlessness, humans can experience different illusions and have spatial disorientations; nevertheless, he believed that it was possible to adapt even to this. After practising, a huge amount of material about psychophysiological changes in the human organism was accumulated around the world. Three main groups of behavioural reaction to the weightless state were experienced and described (Leonov & Lebedev, 1965; Lebedev, 1989; Leonov, Lebedev, & Belitsky, 2001):

1. Aeronauts, who do not feel any drastic change and do not lose their productivity, just feel some relaxation and lightness due to weightlessness. Yurij Gagarin wrote after his first flight: “I looked at the device. It showed the weightlessness. I felt a pleasant lightness. I tried to move. I orientated freely in space”.
2. People of the second group felt an illusion of falling, overturning, body rotation in an indefinite direction, hanging with head down, etc. They felt anxiety, spatial disorientation, body and space size illusions; often, euphoria occurred (when they had forgotten about the program of the experiment, laughed and were playfully humoured). Some of them felt a distortion of their body scheme: head inflation, for example; others felt that the airplane was turned upside down, though when they looked at the illuminator they saw the earth below. In the following flights the emotions and impressions were not as acute as in the first one, as adaptation had occurred.
3. In the third group there were persons who had space illusion and disorientation more severely; it lasted throughout the whole period of the weightlessness and sometimes had symptoms as in seasickness. In extreme cases, the illusions were very strong, accompanied by a feeling of horror, involuntary shouts (cries) and sudden increases of movement activation. They had total space disorientation and loss of contact with other people. It was felt like the symptom of “world crush”

encountered in many brain illnesses. Shmarian (cited in Leonov & Lebedev, 1965) described that the patient felt a sudden headache and dizziness and fell down. “The buildings suddenly became big or small. The darkness had appeared. Everything was falling, becoming strange, unfamiliar and alien… It was like a high speed movie, where the earth was like a boiling cauldron or volcano. Nature dies, people die as well, as in a world catastrophe”. He felt a strong fear, anguish and anxiety, and he cried. Kitaev-Smik observed a pilot during weightlessness: “He had grasping and lifting movements, involuntary cries and an unusual facial expression (the eyebrows were raised, the pupils were dilated, the mouth was open, and the mandible was dropped).” He maintained this reaction during all the period one entire period of weightlessness, so that the doctor could not “reach” him for conversation. Afterwards the pilot shared his experienced feelings: “I did not understand that it was the moment of weightlessness. I felt a sudden feeling of falling, and that everything was disintegrating around. I felt afraid and could not understand what had been happening around me”. He could not remember what expressions he had; and when this was shown the recorded film, he was very surprised by it.

EGG results proved that weightlessness worked as a powerful excitatory stimulus; for this reason, people who had weak nervous systems had greater space disorientation and felt the “world crush”symptom, while people with strong nervous systems just felt positive (sthenic) emotions. Moreover, the reactions that appeared during the weightlessness flights correlated to reactions in other stressful situations (such as during parachute jumping, etc.). However, even in people with strong nervous systems, these flights through vestibular-proprioceptive stimuli had become habitual, and people could experience emotional-neurotic breakdowns (reactive neurosis) in cases of astenisation and chronic fatigue (Leonov & Lebedev, 1965).

If proprioception on a first level involves afferent signals to the Central Nervous System (CNS), at the second level it comprises a feeling of parts of the body as their projection in a cortex. The above-mentioned somatosensory homunculus is also believed to be related to Phantom Limb Syndrome: when a person continues to feel a limb or other amputated part of body (appendix, tooth, etc.) (Ramachandran & Hirstein, 1998; *Phantom limb*, 2009). Phantom sensations can occur as passive proprioceptive sensations of the limb's presence, or more active sensations such as perceived movement, pressure, pain, itching or temperature. The missing limb often feels shorter and may feel as if it is in a distorted and painful position. Occasionally, the pain can be made worse by stress, anxiety, and weather changes (Arena, Sherman, Bruno & Smith, 1990; *Phantom limb*, 2009), and the intensity and continuity of the illusory perception can depend on individual differences. Thus, positive significant correlations were found between neuroticism and evocation latencies; while the intensity and continuity of the illusory sensations were significantly described with more amplitude by extroverts in comparison to introverts (Juhel & Neiger, 1993).

. Since the proprioceptive sense is often unnoticed because humans adapt to it (it is an effect of habituation or desensitization to a continuously-present stimulus), we can become aware of it when we lose it. Particular cases of induced proprioceptive loss are local anaesthesia before operations: teeth or some part of the body before a surgical intervention. Temporary loss or impairment of proprioception may apparently happen periodically during growth, mostly during adolescence, or might be altered when large increases or decrises in bodyweight/size occur due to fluctuations of fat (liposuction, rapid fat loss, rapid fat gain) and muscle content (bodybuilding, anabolic steroids, catabolises/starvation) or in those who gain new levels of flexibility, stretching, and contortion. Proprioception can also be altered by drugs or other chemical substances such as intaking vitamin B6 (*Proprioception*[b], 2003), L-dopa (Mongeon, Blanchet, & Messier, 2009; Sacks, 1976) or chemotherapy. It can also be caused by illnesses: viral infection like in the Ian Waterman case and joint hypermobility or Ehlers-Danlos Syndrome (a genetic condition that results in weak connective tissue throughout the body) (*Proprioception*[b], 2003). Moreover, proprioceptive sense and related to it body size performance can be altered by vibration (Longo, Kammers, Gomi, Tsakiris, and Haggand, 2009).

At present there is in fact no clear definition of proprioception: a part from being narrowly connected to equilibrioception (balance), proprioception is sometimes interchangeable with kinaesthesia, although the latter specifically excludes the sense of equilibrium or balance and can be counted as a subset of proprioception (*Proprioception*[a], 2007). Although we have always had the basic sense of proprioception and despitethe fact that scientists started to pay the attention to it at the end of the 19th century, almost hundred years later questions related to proprioception, still in the article “Were from the Sherrington sense originates from?”, were still unclear (Matthews, 1982). Other definitions of proprioception appeared later. One of them included a broader context of proprioception that was based not only on pure physiological sense, but also expanded to the “self-perception of thought” in which thought is aware of its movements (Bohm, 2007). Previously, proprioception was one of the components of “self” (“I”) or “ego” that was expanded in the theory of psychology by Gordon Allport (*Gordon Allport*, 2006), who operated using the term of “proprium” (“my own” from Latin) instead. Following his ideas, the development of “proprium” has eight stages in order to be mature, the first of comprises a proprioceptive awareness that together with interoceptive and touch sense were a basis of the whole “self” or “proprium” construction and development, or “propriate” functions:

1. **The Sense of Body or Bodily Self** (develops in the first two years of life) is a sense or awareness of one's body and its sensations; it is a basic axis of personality development, an anchor for self-awareness. Here, all body organic feelings are included even though we had not been aware of them until some painful or unpleasant feeling appeared. We perceive everything related to our body as something warm, close and pleasant; and everything alien to it as something cold, distant and unpleasant. Allport's favourite demonstration of this aspect: Imagine splitting saliva into a cup – and then drinking it down! What's the problem? It's the same stuff you swallow all day long; however, it has left your bodily self and thereby become foreign to you.
2. **The Sense of Self-Identity** (develops in the first two years) – is a sense which is growing gradually and is most evident when the child, through acquiring language, recognizes himself as a distinct and constant point of reference. First children recognize their name among the flood of sounds, and later they understand that they are the same person despite external (changes due to growth) and internal (thought) changes.
3. **The Sense of Self-Esteem or Pride,** which is an individual's evaluation of himself and the urge to want to do everything for oneself and take all of the credit. It is an exaltation of ego; the ego that is inherent to man by nature and needed for survival. Everyone tends to self-assertion, must have a sense of pride in themselves, be self-satisfied. It is a time when we recognise that we have value, to others and to ourselves. This is especially tied to a continuing development of our competencies.
4. **The Sense of Self-Extension** (occurs during the third year of life), which states that even though some things are not inside my physical body they are still very much a part of my life. Certain things, people, and events around us also come to be thought of as central and warm, essential to existence. Some people define themselves in terms of their parents, spouse, or children, their clan, gang, community, college or nation. Some find their identity

in activities: I'm a psychologist, a student, a bricklayer. Some find identity in a place: my house, my home town. When their child does something wrong, parents can feel guilty about it. If someone scratches our car, we can feel like they just punched us. While at a early age, the child is identifying himself with his parents or joys that "pertain" to him, later this feeling is extended to other social groups (classmates, neighbours, and nation). At mature age this process can be expanded to the processes of development of abstract ideas and moral values.

5. **Self-Image (**develops between four and six), or how others view "me", is another aspect of selfhood that emerges during childhood. This is the "looking-glass self," as others see me. This is the impression I make on others, my appearance my social esteem or status, including my sexual identity. It is the beginning of consciousness, ideal self, and persona.

6. **Sense of Self as a Rational Coping being** (occurs between the ages of six and twelve), when the rational capacity to find solutions to life's problems appears. This sense is related to abstract thinking and planning, and allows people to cope effectively with the demands of reality.
7. **Propriate Striving or Motivation** (the core problem for the adolescent accounting to Allport; normally develops after twelve). It is the selection of occupation or other life goal, when adolescents know that their future must follow a plan, and in this sense it makes them lose their childhood. It is related to forming the ideal view of our self and direction for future development (where an intentional drive takes over from natural desires and impulses) and is more closely related to reflecingt interest, tendency, disposition, anticipation, planning, problem solving, focus and intention. This is our self as goals, ideals, plans, vocations, callings, a sense of direction, a sense of purpose.
8. **Self as Knower or as Subject of knowledge** - a feature that, according to Allport, rises above the rest of propriate functions and synthesises them. It lies in the fact that man

knows not only the objects of matter, but also himself, resulting in the development of man's capacity for self-knowledge and self-awareness. The knower (thinking agent) “rides” on top of them. The thinker is different from his or her thoughts.

The first three functions – senses of body, of self-identity and self-esteem – are developed in early childhood. The other functions are enlarged over time and depend on individual features of men, own life path or experience. Gordon Allport emphasized that at any stage of personality development, not just one propriative function is developed but a fusion of several. For example, in the situation of maturation of self-understanding, rational subject of proprium, personal motivation (striving), an extension of “ego” and self-image are activated. After Gordon, proprium is a positive quality of human nature, related to creative personality development. He was simultaneously a believer in the uniqueness of the individual and wholeness of personality.

Corr and Mattews (cited in Corr, 2010) noted in their Introduction to the *Cambridge Handbook of Personality Psychology:*

A persistent theme… has been the multi-layered nature of personality, expressed in individual differences in neural functioning, in cognition and information-processing, and in social relationships. Abnormal personality too is expressed at multiple levels. Despite the inevitable difficulties, a major task for future research is to develop models of personality that integrate these different processes.

The multilayered presentation of the human being is represented by the collective unconscious depicted in traditional souvenirs, such as “Matryoshka” that was popular not only in Russia, but also in Japan and other East European countries (Fig. 1.1.3).

Figure 1.1.3. "Matryoshka", a traditional Eastern souvenir, represents a multilevel personality model (bio-psi-social-historical). Inside it is reminiscent of a Universe model (photo and picture adapted by author). (Liutsko, 2013)

Despite some common personality traits in persons, their similarity in body composition, the most integrative picture is obtained at the level of individual description, performed by singular case studies, such as was described by neuropsychologist Luria (1968, 1972) and Oliver Sacks (1985). This tendency towards description of the complete picture that can be done only on an individual level was reflected by modern scientific research in the areas of Individual Differences and Psychology of Individuality conference in Moscow (Russia) in 2012. Each person is a microcosm, a mini-Universe that reflects the external world with individual features. The exteroceptive senses "adjust" our perception and reduce the individual internal variability which is more fully expressed by the proprioceptive sense and independent of external influence (Enoka, 2002).

As an example of range of individual variability between fine graphomotor performance of individuals in condition with vision (PV) and in proprioceptive (P) only, when the participant did not see either the graphical feedback of his drawings nor own hand position is represented on Figure 1.1.4 (Tous-Ral & Liutsko, 2012; Liutsko & Tous-Ral, 2012). MANOVA analysis had shown the significant differences between fine graphomotor performances comparing both sensory conditions (PV vs. P) (Tous-Ral, Muiños, Liutsko, &

Forero, 2012). For this reason, the proprioceptive sense was used by Prof Tous (2008) to create the Proprioceptive Diagnosis of Temperament and Character (Tous Ral, Muiños, Tous López, & Tous Rovirosa, 2012), which will be described briefly in Chapter 2.

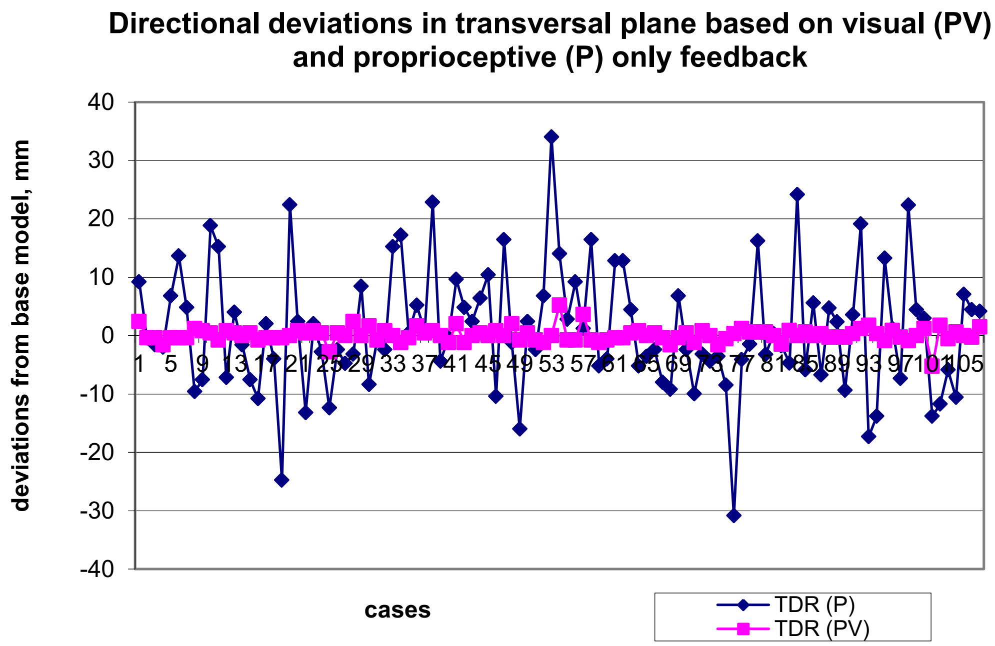


Figure 1.1.4. Comparative graphic of the subject's performances (X-axis) in different sensory conditions: PV – proprioceptive-visual and P – proprioceptive only.

1.2. Learning with the help of proprioception or "embodied" knowledge

In the cognitive sciences, the most challenging phenomena are often the ones we take for granted in our everyday lives.

Botvinick (2004)

[G]*rowing interest in the notion of embodiment has led to a much broader acknowledgement that the mind can only be understood in the context of different interactions with* *other agents and the environment.*

(Sebanz, Knoblich & Humphreys, 2008)

Proprioception plays an important role in our daily lives (Goble, Noble, & Brown, 2010). Its automatic performance is done mainly on the unconscious level: visceral organ regulation (respiration, heart function, etc.), and locomotive synchronization for balance and optimal kinematics in humans (we have an autopropulsive mechanism that consists of about 600 muscles, 200 bones and several hundred tendons) or in animals (how centipede coordinates all their feet) (Fig. 1.2.1).

Figure 1.2.1. Muscular-joint-skeletal human presentation and centipede (picture adapted by author).

Proprioception is a basis for acquiring the automatic knowledge, sometimes called know-how or “embodied” knowledge (Barsalou, 2008; Sebanz, Knoblich & Humphreys, 2008), of the kind based practical experience, daily routine activity or professional skills. When we start to learn a new skill, such as cycling or driving, we need to see our feet pedalling or our hand changing the gear; however, with time and repeated practice we do it on a proprioceptive level and without visual guidance (Figure 1.2.2.), apparently conducted on autopilot (Lee, Swinnen, & Serrien, 1994).

Figure 1.2.2. Automatized actions: cycling (pedalling), driving (changing gear) and putting a spoon in the mouth (picture adapted by author).

The practical knowledge, due to proprioceptive sense, becomes "embodied" knowledge allowing us to be less stressed during multiple and/or prolonged activities. This type of habits and skills commence work automatically and without our brain control. In order to appreciate it, we could mention the examples of automatized movements from the experiments of the famous Russian physiologist Sechenov, carried out more than 100 years ago (Sechenov, 2013):

1) When a *decapitated* frog's leg was pinched, the frog tried to remove the leg from the stimulus; however, when the leg was daubed with an acid, the frog scrubbed the leg with another part of the body.
2) When a frog *without a brain* was pinched on the table, it started to crawl in order to escape from the stimuli; however, when it was pinched in water, the frog started to swim.

Conclusion: it seems that a frog does not need its head (or brain) to distinguish between different stimuli or environment it was experiencing. These examples were of "rational" behaviour that worked as an automatic conditioned reflex. Corr (2010) pointed out in consideration of importance of multiple levels of behavioural control that require recognition of both (a) the relationship between automatic (reflexive or pre/nonconscious) and controlled (reflective, often with conscious representation) processes and (b) their time pattern (or tardiness of controlled processes and their awareness).

Modern researchers have shown that we become aware of our actions or that controlled processing comes with a lag time of 300-500 msec after the action had been started, i.e. mind followed by brain events (Corr, 2010). In Libet's experiments (cited in Corr, 2010), the removal of the hand from a hot stove had occurred before awareness of the hand touching the stove. Libet recorded by EEG the readiness potential (RP) in a simple task (flexion of finger) that required the participants to note when they experienced performing the "voluntary" action. Evidence was found that "conscious" decision had lagged 350-400 msec approximately after the brain started to initiate the action (cited in Corr, 2010). According to Gray's theory (2004), the control of action consisted in late error detection and correction; i.e. it was related to cognitive processes that interrupt the undesirable automatic brain-behaviour routines and correct for the more adaptive ones. The only doubt still unresolved is whether such reactions will be of brain or of body if we transfer the results of "conscious" or "rational" behaviour of the decapitated frog from the experiments of Sechenov.

Mechanisms of behavioural control (e.g. automatic vs. controlled processing) are fundamental in psychological explanation; and individual differences in these mechanisms may be assumed to play an equally important role in personality psychology.

Corr (2010)

Corr (2010) stresses the importance of distinguishing the information obtained by different types of psychometric. If lexical tests (Big Five or others) may preferentially reflect controlled processing and conscious awareness that codifies important features of society (e.g. appreciation of artistic beauty; Openness), the importance of social interactions (Agreeableness) and following the norm and ethics, established by society

(Conscientiousness); temperamental and biological measures (BIS/BAS and DP-TC), on the other hand, would reflect more dispositional, emotionally-based responses. This information can be more closely related to emotional control (Neuroticism) and Extroversion (it belongs to more automatically-elicited preference, since the preference to go to a lively party or to stay at home is not taken on rational judgment, but more emotionally: likes and dislikes). We act as we feel and wish at the moment, however, when we reply to questionnaires; we can fake an answer that can be more "rational" for our observers (especially in cases of special goals and interests like applying for an attractive job). In this case the replies correspond more to our socially "desirable" behaviour than to our real self. In this case we "supplement" or "modify" our behaviour to fit that accepted by the "norms" and "values" of the specific socio-historical culture of time.

To see how these values and qualities really are formed in children's behaviour, I would like to return to Sechenov's famous work "Reflexi golovnogo mozga" (Sechenov, 2013). He explained that during development children first like the "images" of their toys, and wishes to be like their "heroes". Later, they transfer the qualities of these heroes to their own qualities as a model to follow: to be strong and without fears, to be generous and sympathetic, kind and honest, etc. The child, fusing with the image of his favourite hero, identifies with its qualities and transfers them into his own identity. Playing with his hero (it can be a reproduction of the live examples that surround him as well, parental, close friends or significant teacher figures, imaginary heroes from books, movies or videogames), the child repeats many times the actions of his "model", words and attitudes toward to others, i.e. visual, auditory and action behaviour. Prof Ivannikov (2010) also mentioned in the lecture dedicated to achieving of a socio-historical experience the importance of sense of the main activity of children: "Game (playing) is that type of activity of child, in which the norms of human relationships are discovered and supported."

The issue of embodiment and situated cognition has arisen again recently as a core idea that perception, action, and cognition are shaped by the social context in which we engage with others, suggesting that cognition should be investigated at a group level rather than an individual one (Knoblich, 2008; Sebanz, Knoblich, & Humphreys, 2008). Returning to the developmental growth of children, Sechenov (2013, originally published 1863) described that the "passion" of toys and play pass with time, though deep convictions related to this behaviour remain and can acquire other forms. The boy who played a lot with knights, fighting for high moral values, will conserve his deep conviction to fight for justice: as a soldier, general or advocate, for example, or simply a noble person. For this reason, as my own teacher of psychology said: "Be aware what children are playing at, they play at their Future!" The famous Russian pedagogue, Sukhomlinskij, in his work "I give my heart to children" (1985) mentioned about education:

> *Children should live in the world of beauty, fairy tales, music, painting, fantasy, creativity* (translated by author).

And the following expression of Leo Tolstoy became akin to an aphorism in the field of education (*Aphorism*, 2007):

All moral education of children comes down to good example. *If you live well or intend to live well, and in so far as you succeed in your "goodness" in life, children will have a good education* (translated by author).

One of the modern proofs of one of the aspects of such kinds of "visual" fusion is the activation of somatosensory parts of brains, related to the action the person simply watches in a video game, TV or video record (Lee, Swinnen, & Serrien, 1994; Repp & Knoblich, 2004; Scholz, 2010); this activation is more active when the person is practising this type of activities compared to novels (Repp & Knoblich, 2004).

Moreover, the so-called “mirror system” (formed by mirror neurons) matches observation and execution in goal-related actions and appears to be to some degree a “functional” equivalent somewhere between simulating, observing and performing an action (Sebanz, Knoblich, Stumpf, & Prinz, 2005). People tend to reproduce automatically by internal or imagined replication of the posture they observe, mimicking facial expressions, gestures; and this covert imitation requires the use of implicit knowledge of one’s body (Bosbach, Knoblich, Reed, Cole, & Prinz, 2006). In addition, the use of expert models also has considerable pedagogical support by means of *a perceptual blueprint*, a precise representation of the perceptual demands of the task. The suggestion that viewing of repetitious performance of skills would “imprint into” the behaviour of observers was checked by Lee, Swinnen, & Serrien (1994). They found that the performance of persons who observed the skill prior to their own reproduction of it were better than novices who had not seen it before (Lee, Swinnen, & Serrien, 1994).

1.3. Proprioception and quality of life

1.3.1. Proprioception, motor control and health

Our nature lies in movements; complete calm is death.

Pascal, 1966 (cited in Cole & Montero, 2007)

David Rosenbaum (2005), in his work “The Cinderella of Psychology”, astutely observed that motor control is underestimated in psychology. Proprioception, as a basic sense, was also disregarded due to its more unconscious nature, if we see the traditional classification of senses as also being that it controls all other types of senses. However, with a special focused attention and training in the proper contraction and relaxation of muscle, proprioceptive sensitivity can be understood and used in the process of conscious control of movements (their strength, speed, scale, rhythm and sequence). Proprioception plays an important role in the construction of movements, formation of movement skills and in regulation of muscle tonus. Proprioception also contributes to speech function or speech kinaesthesia and to general physical well-being and sense of cheerfulness; moreover, the proprioceptive signals are powerful activators of the reticular system, and, thus, of the brain cortex (Proprioception[c], 2009).

In the process of ontogenesis, the formation of proprioception starts in the 1st-3rd month of fetal development, and by the moment of birth the proprioceptors and cortical motor analyser reach a high degree of morphological maturity and are able to carry out their functions. The most intensive maturity growth occurs from 3 to 7-8 years old, when it attains 94-98% of the adult brain, and the volume of the cortex zones 74-84%. Morphological and functional formation of the proprioceptors in joints and tendons finishes by the age of 13-14 years, and muscle proprioceptors, by the age of 12-15 (*Detskaya medicina*, 2001).

In healthy adults, proprioception works properly and helps people to carry out their daily domestic and professional tasks, as well as favourite activities (hobbies) that allow them to maintain the quality of life until the aging effects appear (more detail will be discussed in Chapter 3). However, any disturbances in life, stress, trauma and illnesses affect the proprioceptive state that both reflects and is related to physical, emotional and cognitive functions. For example, proprioceptive dysfunction was observed in children with autism: their movements were uncoordinated and clumsy (it was estimated that 80% of subjects with Asperger Syndrome [AS] displayed “motor dyspraxia”), and they performed poorly at one-legged balance with eyes closed (Weimer, Schatz, Lincoln, Ballantyne, & Trauner, 2001) or slowly adapted in comparison to a control group (Izawa, Pekny, Marko, Haswell, Shadmehr, & Mostofsky, 2012). Other studies reported that children with clinically avoidant personality traits showed a significantly poorer motor performance than the control group (Kristensen & Torgersen, 2007), and children with Down's syndrome were significantly lower in scores for both gross and fine motor skills, as well in running speed, balance, strength and visual motor control (Connolly & Michael, 1986). Schmahl and colleagues (2006) reported differences in nociception (pain threshold) for persons with Borderline Disorder (BPD) and found that the average 50% threshold was 43ºC for patients with BPD, while for controls it was only 37.7ºC.

Moreover, postural control was altered in patients with bipolar disorder: sway was increased in the absence of vision (Bolbecker, Hong, Kent, Klaunig, O'Donnell, & Hetrick, 2011), and in a case of obesity (Teasdale, 2012). The existence of a relationship between proprioceptive information in the fine graphomotor drawings and the immune systems (IgG and IgM) was reported in a study conducted by the Mira y Lopez Laboratory (Personality Department, Faculty of Psychology at the University of Barcelona) by Prof Tous and collaborators (Tous, Vidal, Viadé, & Muiños, 2002). Both dysfunctions of proprioceptive and of sensory integration of proprioception and vision (for some movement types) were observed in patients with Parkinson (Gironell, Luitsko, Muiños, & Tous, 2012), persons with personality disorders (Tous, Grau, Viadé, & Muiños, 2005), in the case of persons with aggressive behaviour (Tous, Viadé, Chico, & Muiños, 2002) and prison inmates (Tous, Muiños, Chico, & Viadé, 2004). However, proprioception has a critical role in the reorganization and subsequent recovery of neuromotor systems and this sense is the "most important source of feedback for promoting neural plasticity" (Goble, 2010).

1.3.2. Proprioception relations with attention, memory and emotions

How can a brain have experiences?

The human psyche perceives any external body as really (actually) existing
only due to the idea of the state of one's own body… If a human body is not exposed
to action from any external body, then the idea of human body,
e.g. the human psyche,
is not affected by any action from the side of idea or existence of this body;
in other words, it does not perceive the existence of this body in any way.
Spinoza B., 1957
(cited in Ivannikov, 2010, translated by author)

If we observe how robots move, we can see that their patterns are too standard, mechanical and they cannot assess the force of pressure without which they pick up an object since they that do not have tactile and proprioceptive senses to adjust it according the property of material. The robotic hand can take a bottle and try to fill up the glass; however, it will not stop at the appropriate moment before the glass is full. As the brain does not produce output in the way traditional machines do ("the principal activities of brains are making changes in themselves"), it is self-modifying and dynamic, unlike the standard idea of an organ which exists to represent external states. Rather, the world is itself present in processes of self-modification.

The brain is always already a part of the physical (bodily) and social world. Let us turn for a moment to the brain's skilful behaviour in the world. Biological agents always know very little at a time; they infer a great deal (famous examples include reaching for a cup, or assuming what the trajectory of a ball coming towards us will be, rather than making the actual calculation in our head). Gibson's notion of "affordances" implies that an object contains an infinite amount of information, since it is different for each perceiving individual. N. Bernshtein also concluded that movement is always the problem solution, in which the brain, as a controlled organ of movement, should receive various information inputs, without which the problem of movement coordination cannot be resolved adequately (cited in Ivannikov, 2010). In addition, the cognition itself due to proprioceptive sense and body states allows a multisensory representation of subject to be experienced. Once experienced, the object has more qualities then its simple abstract meaning. For example, after having the experience of easing into a chair, we later relate with a category "chair" what we had obtained from this experience: how the chair looked, what was the tactile sense and "record" of the material it was made of, what we felt sitting there (comfort and relaxation) (Barsalou, 2008). "Grounded cognition" reflects the assumption that cognition is typically grounded in multiple ways: simulations, situated action and sometimes bodily states. For example, a pianist's ability to identify auditory recordings of his/her own playing depends on stimulation of the motor actions underlying it (Repp & Knoblich, 2004). Andy Hamilton (2005) defends the view of proprioceptive knowledge as a perceptual one or as a part of the material from which the latter concepts are formed, a part of direct knowledge we obtain of body states (we do not acquire; we just "know" [feel] that our legs are crossed or that this touch was painful).

Researchers Casile and Giese (cited in Thornton & Knoblich, 2005) showed that motor learning in the non-vision condition can favourably influence later perceptual performance. In spatial memory, proprioception helped to point more accurately to landmarks: better results were obtained when participants walked than when they simply watched the landscape (Yamamoto & Shelton, 2005). In implicit memory, stimulations increase perceptual fluency and the likelihood that perceptions are categorized correctly; and motor simulations present in comprehension. Thus, when participants simply read the word for an action, the motor system became active to represent its meaning (Barsalou, 2008). Moreover, the presence of affective simulation was shown: when people read taboo words, the stronger affective reactions (measured by skin conductance) were found when they read in their first language than in a second one, acquired at later age (Harris, Aycicegi, Berko, & Gleason, 2003). However, it was found that individual differences in skills, such as ballet correlated with an ability to mirror relevant action (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005).

Conscious mental states possess intentionality, the faculty of being 'about' something, and thus the substrate of these states, the brain, is more than an organ for rapidly initiating the next move in a real-world situation, and the historical nature of an organism is more than the sum of its adaptive responses. Skill is a revealing case of how we deal with challenges from the environment, mobilizing our resources in real time. Proprioception helps to have dynamic responses in our individual behaviour, e.g. one's hand to reach for an object should calculate all variables of the trajectory, doing manipulation, re-shaping, and taking in of information. The brain is not the "central planner" but during the development possesses of the vehicles humans employ (language, culture and institutions empower cognitions) this quality is inseparable from the external world.

From Mosby's Medical, Nursing and Allied Health Dictionary, "Proprioception is "one's own", "individual" perception…" (*Proprioception*[d], 1994), while from Enoka (2002), proprioceptive muscular activity is independent of external stimulation, being generated by the organism itself and recorded by muscular sensorial receptors or proprioceptive organs such as spindles, Golgi tendons or synovi joints. Results of independence of automatic handwriting movements of visual feedback were presented by other researchers (Marquardt, Gentz, & Mai, 1999). The sensorial integration of proprioceptive information together with extereoceptive information has been well studied; and it was accepted that proprioception is necessary for the individual to carry out the tasks with precision (O'Dwyer, & Neilson, 2000; Laiteiner, & Sainburg, 2003; Fuentes & Bastian, 2010). Neurologists propose the mental construct of motor planning to explain intentional motor behaviour, which is related with motor cortical areas, whose functioning is based on extereoceptive and proprioceptive information (Ito, 1984; Serratrice & Habib, 1993; Horlingsa, 2009). Neurophysiologists such as R. J. van Beers have studied differences between visual and proprioceptive information (van Beers, Sitting, & Denien van Gon, 1996); sensomotorial integration between vision and proprioception (van Beers, Sitting, & Denien van Gon, 1999; van Beers, Wolpert, & Haggard, 2001), and the precision of proprioceptive sense in 2D space (van Beers, Sitting, & Denien van Gon, 1998).

Recently, the role of proprioceptive information has emerged in different areas of research, and a greater number of publications have appeared outlining differences in the domain of vision and proprioception and their integrative function under different set-up conditions (see Ghafouri & Lesstienne, 2006; Touzalin-Chretien, Ehrler, & Dufour, 2009; Laiteiner & Sainburg, 2003; Meyer & Saglovden, 2006; Smith, Crawford, Proske, Taylor, & Gandevia, 2009 among others). Despite difficulties in measuring pure proprioceptive information, there were some attempts to map proprioception areas across a 2D horizontal workspace (Wilson, Wong, & Gribble, 2010). However, the nature of movement variability (van Beers, 2007) as well as integration of the eye-centred (PV) and body-centred (P) integration scheme (Beurze, Pelt, & Medendorp, 2006) is as yet poorly understood. The importance of understanding the nature of individual differences in proprioception sense via fine hand-drawing movements and how this information can be applied for educational and clinical aims has already been discussed (Tous, Viadé, & Muiños, 2007; Accardo, Chiap, Borean, Bravar, Zoia, Carrozzi, & Scabar, 2007; Chang & Yu 2009; Mergl, Juckel, Rihl, Henkel, Karner, Tigges, *et al*, 2004; Sabbe, Hulstijn, van Hoof, & Zitmans, 1996); although this topic had previously been neglected along with motor control in the science of mental life and behaviour (Rosenbaum, 2005).

Individual behaviour is generally considered to be limited only by intentions, which are the final result of all our mental processes. However, individual behavioural responsibility should be considered from a dual perspective: the first corresponds to the intentional component (mental contents), while the second is related to our body (the somatic basis that provides the dispositional component of behaviour).

(Tous-Ral *et al*., 2012, translated by author).

To sum up, there are two parts of our behaviour: 1) volition (conscious or unconscious) and 2) possibility (biological basis and limits), the first to be implemented.

The study of motor control (Rosenbaum, 2005) has shown that an intention can only be executed if it is accompanied by the necessary motor activity. As such, the motor component plays an important role in the selection of our intentions. Indeed, the execution of any human act is based on interaction between intentions and dispositions and is a higher-order process that is closely linked to cognitive processes. For example, Ingram, van Donkelaar, Vercher, Gauthier and Miall (2000) demonstrated that cognitive performance (attention) depends on proprioception. These authors found that when attention was interfered with, control subjects showed a 10% drop in task performance, whereas the corresponding reduction in a subject without proprioception was 60%. A similar conclusion was reached by van Beers, Sittig and Denier van der Gon (1998), who showed that individuals without proprioception need to pay greater attention to the task than do people who have it. Veira and colleagues (Veira, Quercia, Michel, Pozzo, & Bonnetblanc, 2009; Barela, Dias, Godoi, Viana, de Freitas, 2011) investigated whether postural control was impaired in dyslexic children if cognitive demands had been increased, and they demonstrated that mean velocity (i.e. the total length) of centre of pressure (CoP) displacement had been increased in reading tasks only for the dyslexic group. Their results supported the hypothesis of a cerebellar origin for dyslexia. Maylor, Allison and Wing (2001) found that postural stability, or balance, which is closely related to the proprioceptive sense, can be affected by cognitive activity in complex ways, depending on age of participants, type of cognitive task (they were less stable in nonspatial tasks compared to spatial), and the cognitive processing required (they were less stable during maintenance compared to encoding).

Experiments with infants (of neonatal age and 9 months) proved the existence of a link between locomotor experience and later emotional expressiveness (Uchiyama *et al.,* 2008). Other researchers demonstrated that proprioception "encodes" the affective information of movement. Neumann and Strack (2000) showed in their experiments that approach movements facilitate the positive affective concepts, while avoidance movements facilitate the negative. As far as the proprioceptive contribution to emotion is concerned, not only facial feedback plays an important role (since skeletal muscle afferent signals from facial expressions play a causal role in regulating emotional experience and behaviour); it has also suggested that visceral feedback may have more direct effect (Buck, 1980).

The general relationship that the worse (less precisely) the proprioceptive sense works, the more abnormalities in health can be encountered is not true. The proprioceptive sense can be "sharper" or more precise in persons with somatoform disorders (Scholz, Ott, & Sarnoch, 2001) or can be used more in comparison to other exteroceptive sense (vision) in persons with autism. Thus researchers from Kennedy Krieger Institute and John Hopkins University School of Medicine (published in Neuroscience Letter) found that children with autism learn new actions differently to control: they rely more on the proprioceptive sense than on visual cues. Furthermore, researchers found that the greater the reliance on proprioception, the greater the child's impairment in social skills, motor skills and imitation (Kennedy Krieger Institute, 2009).

Proprioceptive information allows us not only obtaining some kind of screening about the physiological, emotional and cognitive state of a person, but also explains his individual differences and bio-social dispositional behaviour. The strong behavioural tendencies, which can be considered as "abnormal" or "rare", could be both of non-adaptive (pathological) and of adaptive (talented) types. Sometimes even the neurobiological components could be at the same level (Manzano, Cervenka, Karabanov, Farde, Ullén, & Rustichini, 2010). For this reason the person who makes a diagnosis has a great responsibility and should be very careful and sensitive to distinguish between the two cases. If a person leads a non-destructive life for himself and others, and his "odd" traits do not disturb but rather help him to realize himself by creativity or other qualities that distinguish him from the "normal mean", maybe there is no need for "treatment" or for destroying his own integrity as existing thus far. Are we going to design a "treatment" to "restore" the person to normal IQ if he exceeds the normal levels? In this case, it is nevertheless clear as in case of personality and individual differences the situation tends to bias towards characterising the "abnormal" almost always as "pathological" behaviour.

Unfortunately there is no any objective "tool" that will allow diagnostic errors made by professionals to be reduced, and still less for individuals, since "if you have a mental illness, you cannot recognize your state by yourself", meaning that we ignore patient's opinion and feelings and will base diagnosis on our external assessment that is often not complete. For these reasons, more non-verbal and objective methods are needed, especially for the cases when the "mental" health state can be manipulated for private interests (in justice) or ideological-political repression, as when many intelligent, artistic and religious people were sent to Siberia to concentration camps as being "inadequate" or placed in psychiatrist clinics with wrong diagnosis just to keep them there as persons with mental "disorders", described in autobiographical histories similar to Solzhenitsyn's *Archipelag Gulag* [*Arkhipelag GULAG, originally published in Russian in 1973*], a prisoner in a Gulag labour camp (Solzhenitsyn, 1973). For this and other sociohistoric events, Mira y López said that *it is difficult to be healthy in a sick society,* and he considered a personality of a bio-psi-social construct. Luria and Vigotskii (Thvostov, 2012) also mentioned the importance of society (historic-cultural approach) in forming the personality, regarding socio-historical influence as one of the important issues. This socio-historical and cultural aspect is "saved" and can be observed in the external language of behaviour – how people dress, speak, gesticulate, and if they are more quiet, closed and timid or more expressive and open.

1.3.3. Ways of improving proprioception

In reflecting about cause-effect relationships, although scientists with their logical rationality like to have recourse to linear dependence, from the practical point of view live models are usually more complex and often work in both directions simultaneously: the effect can play a causal role and vice versa. Sometimes it is quite difficult to determine or distinguish between the supposed cause and effect or to place one before the other. Moreover, proprioceptive "dysfunctions" can occur due to multiple causes that can be controlled at the external level by proper individuum (developmental and maturation processes; training, acquisition of constructive or good habits, emotional intelligence; leading a healthy life style) or by the environment, e.g. society and its development. Once conflict had arisen, we can reflect on it, its negative consequences and can choose another way to behave, changing the behaviour (both at individual or collective level). For example, accelerated economic development and use of natural resources resulted in negative consequences from such human activity, and by 1972 the First Environmental consciousness issues were proclaimed, the start of sustainable development. After discovering that pesticides and heavy metals affected our health (they also are one of the causes of Parkinson disease), they were prohibited. These questions about our individual health were due to collective "normative" behaviour. Previously, many people who were exposed to radiation or other toxic elements during accidents or just by working at certain factories did not even know about the environmental effects on their health. As well as health issues and good quality of life, in order to improve them we also need regulation aimed at the best behaviour of individuals and on a social level. The cause-effect relationship of effectiveness of this change is similar to the chicken-egg paradigm. On the one hand, it seems to be simpler to start at an individual level; however, the "abnormalities" would be returned to the start point due to the social "normative" and acceptance patterns. It is akin to vicious cycle, where "*the head bites its own tail*".

In this chapter, I will still talk about individual control changes to improve our proprioception and health and quality of life; although sometimes environmental factors (both nature and society) should not be disregarded, especially when they play a crucial role in our state. There are factors that we control only to a certain extent, but not totally, like the natural aging process, which can be different (more or less qualitative), though, we cannot extinguish it fully. The summarized description of the main factors of control to improve our proprioception, which is an indicator of own state (physical health, emotional and cognitive states), is represented in Figure 1.3.3.1. These factors that help to maintain our proprioceptive state in better condition are the following:

1) Regular physical exercise;

2) Quality nutrition;

3) Emotional control or Emotional Intelligence;

4) “Good” or constructive skills, habit and traditions. Mastering or improving in professional and other skills. Healthy life style.

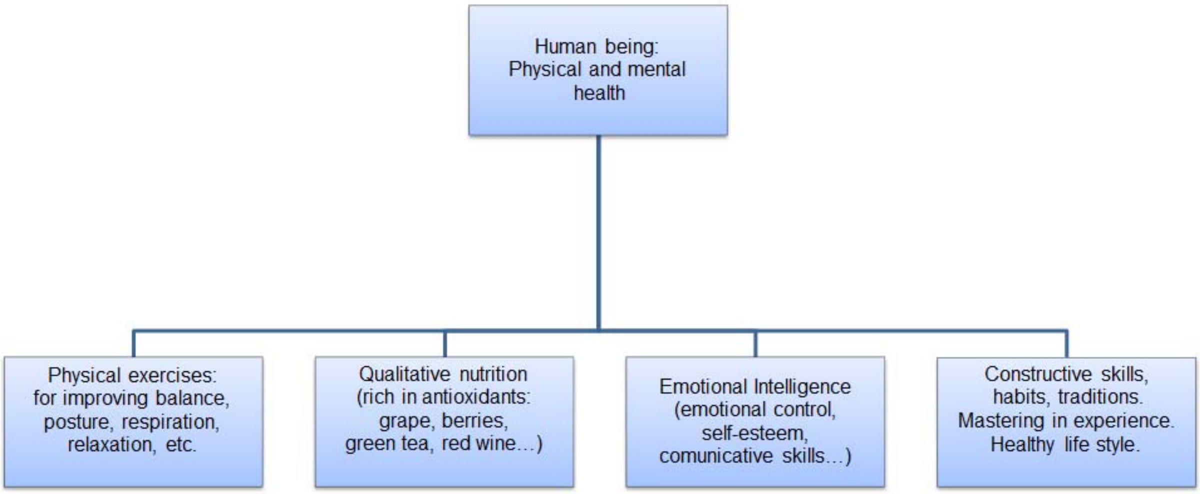


Figure 1.3.3.1. Proprioception: factors of control.

Regular physical exercise

Kelaher, Glasscock, and Mirka (2007) reported their finding concerning the existence of a strong correlation between the overall repositioning of trunk and the combined score of the Kinetic and Proprioceptive Assessment Questionnaire and the Body Awareness Questionnaire. Gellhorn (1964) pointed out that various “relaxation” therapies alleviate states of abnormal emotional tension by reducing proprioceptive impulses which impinge on the posterior hypothalamus and maintain the cerebral cortex in an abnormal state of excitation.

Physical exercises, especially those that are related to improving equilibrium (balance), relaxation, proper respiration and proprioceptive consciousness such as Yoga, Tai-Chi, Pilates, etc., as well as dancing and singing, can be useful. For example, the slow and focused movements of Tai Chi practice provide an environment wherein the proprioceptive information being fed back to the brain stimulates an intense, dynamic "listening environment" to further enhance mind/body integration. Several studies have been done to show their effectiveness and that of other physical and proprioceptive exercises for balance, good emotional state and reducing aging affects (Lelard, Doutrellot, Pascal, & Ahmaidi, 2010; Tse & Bailey, 1992; Shin, 1999). The Alexander Technique uses the study of movement to enhance kinaesthetic judgment of effort and location; juggling trains reaction time, spatial location, and efficient movement; and standing on a wobble board or balance board is often used to retrain or increase proprioception abilities (Proprioception[a], 2007). Moreover, there was found to be a positive correlation between dancing and general, fluid intelligences and working memory (Fredyk & Smal, 2012). Another ancient Slavic method (Fig. 1.3.3.2), called “Pravilo” (with emphasis on “i” in Russian meaning “Correction”), is used to balance internal energy and stretch both muscles and joints removing the clamps and physical blocks, helping the discovery of hidden reserves and creativity, promoting health. This tradition was used by Slavic defenders before combat with enemies to reduce fear and to be prepared for extreme situations (*Pravilo*, 2011).

Figure 1.3.3.2. “PRAVILO” method to stretch and balance internal energy (author: Zaitsev, S.) (used with permission).

Quality nutrition

In general healthy (and prudent quantities of) food is the main source of human physical being and activity, as well as of mood or emotional state. However, some elements rich in vitamins C and E, and flavonoids were found to have an antioxidant effect and thus be effective in improving proprioception, such as berries, grapes, green tea, red wine (Seroka, 2011; Willis, Shkitt-Hale, & Joseph, 2009; Berg, Kirkham, Wang, Frísen, & Simon, 2011; Willis *at al.*, 2009). Moreover, healthy diet helps to avoid overweight, which has effects on human balance, as in its turn closely related to proprioception (Teasdale, 2012).

Emotional control or Emotional Intelligence

Although all of us had “bad” models we acquired and followed automatically during our development, maturation or our whole life (*there is no end to perfection*), sometimes it seems very difficult to “forget” the wrong or destructive habit. Since it was repeated hundreds or thousands of times and was “incrusted” in our “natural” behaviour, we consider that “we are like this”. For sure, both cognitive and conscious control together with strong will and persistence are required to substitute a destructive habit with another, more healthy (for us) and appropriate (for both us and the environment) one. A large store of patience is needed to change the “old” custom, and sometimes also the support of others. Constant awareness, attention and self-control help in reaching a new model to replace an old one. However, the “proprioceptive” principle will sooner or later work and give desirable results. As the Russian traditional proverb says, “Repetition is the Mother of Learning”; and it can be applied not only to abstract and cognitive learning, but also to “embodied” knowledge, and it is the crucial factor in one formation of good habits or professional skills.

He who always wears the mask of a friendly man must at last gain a power over friendliness of disposition, without which the expression itself of friendliness is not to be gained- and finally friendliness of disposition gains the ascendancy over him: he is benevolent.

Friedrich Nietzche (1876) (cited in Gellhorn, 1964, p. 457)

Moreover, this change (new action) has an influence on perception: for example James (1922) proposed that expressive behaviour affects the intensity of emotions; a finding that was supported by research experiments (McArthur, Solomon, & Jaffe, 1980).

In addition, Cole and Montero (2007) focused on a possible second role of the sixth sense (or proprioception) as an affective proprioception (similar to affective touch), which contributes to pleasure in and through a movement, which people can perceive, prticularly professional dancers, musicians and sportsmen. Richard Shusterman (2000) distinguished two concepts: awareness of the body's external form of presentation (body builders and photomodels) and lived experience (how our bodies feel in moving). Gallagher (cited in Legrand, 2007) stated "that difference between body image and body schema is like the difference between having a perception of (or belief about, or emotional attitude towards) one's body and having a capacity to move one's own body". More specifically, he pointed out that the body schema would sometimes involve a pre-reflective experience, while the body image would sometimes involve observational consciousness of the body.

"Good" or constructive skills, habit and traditions. Mastering or improving in professional and other skills. Maintaining a healthy life style.

From ne hand, stress reduces the defences of the immune system, accelerates aging processes and "takes its toll in Parkinson disease" as mentioned in the title of the article published in Science Daily (Nov. 11, 2012) due to superoxidation and free radical formation

(Guzman *et al*., 2010). For this reason both emotional control abilities and constructive habits and skills are required to maintain a healthy life style. Persons with personalities non-adaptive to stress have higher risk of certain illnesses: of type C are more vulnerable to infection and cancer, while of type A have twice the chance of suffering a sudden coronary disease (Robles Ortega & Peralta Ramírez, 2006). An acquisition of emotional competencies not only helps in the interactions of professional life, but also helps to create less stressful situations in communication at family level (Salovey & Mayer, 1990; Gippeneiter, 2007).

From another hand, mastering skills helps to reduce stress since with time the skill does not require full attention and cognitive effort to implement it, allowing become more automatic. This autopilot performance lets us not only be more relaxed during the action, but also allows us to combine multiple actions at the same time.

In addition, negative correlations were found between fine motor precision in the proprioceptive condition of test and our mnemonic memory and academic performance in secondary school pupils (Liutsko, Muiños, & Tous, 2012). Moreover, it was proved that mastering certain activities helped to improve the performance of others. Thus it was shown that musical activities, such as playing the piano or flute, had positive effects on the development of kinetic and spatial functions of children, and in turn resulted in better academic performance (Glozman & Pavlov, 2007).

CHAPTER 2. OBJECTIVES OF THE STUDY AND BIBLIOGRAPHICAL REVIEW

2.1. Objectives of the study and its importance

General objective:

The global aim of this work is to provide the psychological (neuropsychological) discipline with a wide bibliographical review about proprioception and its role in human health and quality of life on the one hand. On the other hand, another experimental aim was to contribute to differential and developmental psychology a study of proprioceptive fine motor behaviour and age and/or sex dependent differences.

Moreover, in this work, a description of Proprioceptive Diagnosis of Temperament and Character is briefly given, as a methodology, developed by Dr Tous and colleagues within tradition of Mira y Lopez works with use of new technologies. The results of the thesis work, together with other recent studies carried out at the Mira y Lopez Laboratory, contribute to the methodological and practical use of the technique. The age and sex dependent differences allow to tune the standardisation of T-scores in applicative form of the methodology to be more consistent and robust for the final interpretation by specialists who use it either in psychological and therapeutic works or in personal selection (human resources, driver or gun licence applicants or in other areas, especially related to responsibility for other people's lives).

This study encompasses various scientific areas such as basic psychology and individual differences, neuropsychology, psychiatry and medicine and has practical implications for therapy and health prevention, coaching and education as a partial contribution to general comprehension of intrinsic human behaviour predispositions. The information provided in this work can help also to achieve deeper understanding of maturity and aging processes, since proprioception is crucial in both basic and professional (or skilled) automatic behaviour; and generally allows a lessening of the stress in complex human action by reducing of use of cognitive resources (focused attention) for other purposes like balance and simple mechanical actions. It is the first experimental confirmation of ages of maximum maturing and starting of aging that confirm the mid-life crisis ages (35-45). Different movement types and hands would reflect other peculiarities and inflection points in different movement can report different developmental stages or hormonal interaction as well. The knowledge about of ages that could be related to hormonal changes and proprioception is important in order to make planned interventions. This is a practice realized in the famous Russian clinic of Fedorov (interventions for vision) take into account of hormonal changes – punctual, like a pregnancy or experimentally known physiological cycles since it the results of operations are more prolonged if they done after these changes (in case if the operations were done before hormonal changes, there is a higher risk of vision deterioration again). Thus, knowing when proprioception is changing (points of changes) can be taken into account also by medical workers. These periods will be critical and vulnerable for psychological changes in the individuum and can be taken into account in psychological help.

Specific objectives:

To produce a synthetic bibliographic work on the topic "Proprioception and its importance in human life" due to scarce material and attention presented in educational textbooks on it and the increased interest paid to proprioceptive sense in other areas of those traditionally used, such as medicine and sport. Recently, proprioception became a core of interest of engineering and computering, neuropsychological and neurological researches a part of physiologists' and medical workers' activities in the sport area. The aim is to provide a literature review based on original sources of both historical personalities and modern researchers from various countries and authors of original works (sometimes not published in English, but in Russian or Spanish only) concerned the topic of proprioception and its implications for health and quality of life. This broad view from different epochs and mentalities allows the building of complex information on the topic, brought together by pieces from multiple sources.

1. The second main aim of this dissertation is proper exploratory research on whether there exist age and sex dependent differences in fine motor behaviour, especially in proprioceptive (P) test condition when movement is not controlled by exteroceptive senses such as vision or touch. Motor behaviour without exteroceptive control (in P-test condition) can differ from that controlled by vision (proprioceptive-visual, PV-test) since participants do not obtain feedback about their tracing or active hand position and for this reason cannot modify it. Thus, in P-test condition we can observe the intrinsic individual differences trends in fine motor behaviour which can be based on particularities of neuro-humoral system on the one hand (especially seen in the non-dominant hand) and adaptive behaviour which a person obtained due to environmental changes (dominant hand, since it is the active one used in everyday activities). The aim of this research to check and describe the age and sex dependent differences if any exists in participants with ages from 12 to 95.

   Detailed objectives of this research are described by the following questions or aims:

   a) to describe changes in precision and velocity fine motor precision dependent on age of participants: whether they are linear and non-linear. And if the hypothesis concerns polynomial age-precision and age-velocity dependence, if it is possible (if they are quadratic) to find the inflection points of corresponded ages;

b) to check whether hand symmetry/asymmetry in performance and velocity is changing with age;

c) to verify the existence of any sex/gender dependent differences in fine motor precision and velocity and to see whether they change or remain constant with age;

d) to study if there exist hand symmetry/asymmetry at statistical level in each sex subgroup;

e) to check for a precision-speed relationship for both hands (ND vs. D) and both sensory conditions (PV vs. P);

f) to describe study limitations and future research perspectives in order to enhance the correct methodological use and interpretations of results, avoiding the "narrowness" in diagnostics that is always biased toward negative interpretations instead of seeing both ways (destructive as a pathotology and constructive as a opportunity for positive changes).

Thesis structure:

To sum up, the aim of Chapter 1 (Introduction) has been to describe the little defined sense of proprioception, to see how individual differences are based on proprioception and formed by education, to show the importance of this sense for health and quality of life, and how to maintain the proprioceptive state in the most optimal condition. Chapter 2 describes the importance and goals of this work together with bibliographic reviews on specific topics of study (age and sex differences in motor control and proprioception). Chapter 3 is devoted to methodology that was developed in Laboratory of Mira y López under the direction of Prof Josep Maria Tous and the techniques used in the studies of the thesis. Chapters 4 describe the experimental study of age and sex differences in proprioception based on fine motor behaviour. Finally, Chapter 5 will globalize the discovered results, providing main conclusions, practical applications of findings and potential future interest of research on the topic.

2.2. Review of age differences related to proprioception and motor control

The famous riddle of the Sphinx: "Which creature in the morning goes on four legs, at midday on two, and in the evening upon three, and the more legs it has, the weaker it be?" Oedipus solved the riddle by answering: "Man—who crawls on all fours as a baby, then walks on two feet as an adult, and then walks with a cane in old age."

The famous riddle of the Sphinx reflects the developmental trend in motor control at different periods of life: children, adults and elderly persons. Similarly to gross motor performance, other organism's functions went through the same stages in evolution, brain maturity for example. For this reason, the hypothesis that arose for the current study was: would be a similar evolution trend of proprioceptive and visuo-proprioceptive functions in relation to fine motor behaviour throughout the human life span? Although this behaviour can be represented in the form of a complex polynomial pattern, with 'ups' and 'downs' and small cycles within a larger one, generally, it can be simplified into two main developmental stages: the first corresponds to the period of growth and maturation, in which one sees a gradual improvement in motor performance; however, with the passing of time it eventually begins to deteriorate as part of the aging process.

Given that human life expectancy is increasing and the percentage of elderly people is on the rise (especially in developed countries), the question of how to maintain health among the elderly is becoming ever more crucial. An illustration of what is at stake is that fall-related costs for persons over 65 years of age are expected to exceed US $32 billion by the year 2020 (Shaffer & Harrison, 2007).

Thus, research into aging processes and preventive measures to maintain health and life independent from others for us long as possible is open to challenge and requires an integrative approach of different areas. Summarising the research results concerning physiological or neurological changes related to aging, the “crucial” age point can differ, depending on the object of study; however they contribute to seeing the common view of aging at different levels:

- a diverse and nonuniform decline of sensory structure and physiological function across the life span, though accelerated with advanced aging (Shaffer & Harrison, 2007);
- an increase of skin slipperiness, that negatively influences on grip force, starting at the age of 50 (Cole, Rotella, & Harner, 1999);
- great problems in the elderly population (after 50th decade) with equilibrium when visual, proprioceptive or both inputs are altered (Teasdale & Simoneaub, 2001) and an increased variance in the balance performance after 60 years of age (Shaffer & Harrison, 2007);
- a progressive worsening of vision after the age of 50; isometric and dynamic strength of the quadriceps increases up to 30 years old, and decreases after the age of 50; an increased amount of the postural sway after the age of approximately 30 years (Sturnieksa, Georgea, & Lord, 2008);
- as for peripheral sensory innervation changes, the sensory nerve conduction parameters peak at the age of 40 years and subsequently decline (Shaffer & Harrison, 2007);

- evidence of cognitive ability loss in humans during middle age (35-65 years old) (Willis, Shukitt-Hale, & Joseph, 2009) ; and
- the increase in white matter volume peaks at the age 43 and declines thereafter (Sowell, Peterson, Thompson, Welcome, Henkenius, & Toga, 2003).

Lastly, studies relating to the postural control and proprioception are highlighted in order to prevent sensorimotor deficits related with aging (Goble, Coxona, Wenderotha, Impea & Swinnena, 2009) and adapted to a reweighting of the sensory inputs of elderly persons that perturb their balance and that have strong interaction with cognitive processes (Teasdale & Simoneaub, 2001). For these reasons the aim of our study was to see how the proprioceptive together with visuo-proprioceptive information feedbacks, based on the fine motor performance, change depending on age.

Neurological studies based on fMRI analysis (Sowell *et al.*, 2003) have shown that the trajectory of maturation and aging effects displays a complex (and not always linear) pattern and varies over the cortex. Specifically, Sowell and colleagues (2003) found that the density of grey matter declined in a nonlinear way and most rapidly between age 7 and 60 years over dorsal frontal and parietal association cortices. However, the left posterior temporal region showed a gain in grey matter density up to age 30, before entering a rapid decline. As for white matter density, this was found to increase between ages 19 and 40 years, after which it declined. Non-linear effects (quadratic) were observed in total white matter volume, peaking at age of 43 with subsequent decline (Sowell *et al*., 2003). Bartzokis and colleagues also proved the rough quadratic trajectory in myelin content and integrity in the male sample (N=72, age from 23 to 80 years) that reaches a maximum in mid-life and declines in older age (Bartzokis, Lu, Tingus, Mendez, Richard, Peters, Oludawara *et al*., 2010). Motor performance, also, is approximately shaped to the quadratic function, as was shown by Leversen, Haga and Sigmundson (2012) in 338 participants (7-79 yrs, cross-sectional study), increasing from childhood (7-9) to young adulthood (19-25) and subsequently decreasing up to old age (66-80). They nevertheless emphasised in their article that knowledge about general life-span-long development is still insufficient and that studies within motor domain research are sparse (Leversen, Haga, & Sigmundson, 2012). Regarding psychological research, motor control studies are actually underestimated and occupy a "Cinderella" position as compared by Rosenbaum (Rosenbaum, 2005).

With regard to changes in vision and balance, a progressive worsening is usually observed in vision after age 50 and in balance after age 65 (Sturnieksa *et al.*, 2008). Proprioception also decreases with age and is closely related to loss of muscle and joint strength. Muscle strength has been found to peak up to the fifth or sixth decade, but shows a 50% decrease by age 80 (Cole *et al.*, 1999; Sturnieksa *et al.*, 2008). Senior Olympians (>50 years) declined in winning performance by approximately 3.4% per year over 35 years of competition - slowly from age 50 to 75 years and dramatically after age 75 years (Wright & Perricelli, 2008). As far as lateralization is concerned, some researchers have shown decreased hand asymmetry in motor tasks with aging (Przybyla, Haaland, Bagesteiro, & Saiburg, 2011) and a shift towards to ambidexterity (Kalisch, Wilimzig, Kleibel, Tegenthoff, & Dinse, 2006), while others have reported faster work of the right hemisphere (left hand), which did not change much with age on non-verbal and visual tasks (Stern, Oster, & Newport, 1980). Studies of hand asymmetries and age development are still little represented.

The importance of engaging in daily physical activity (Ribeiro & Oliveira, 2007) combined with a diet rich in antioxidants or essential fatty acids (Willis, Shukitt-Hale, & Joseph, 2009) could contribute towards preserving one's proprioceptive function. Moreover, the maintenance of proprioception in good condition or even improving it, as part of general health, can also improve cognitive state and, subsequently, quality of life. For example, negative correlations were found between some indicators of fine motor imprecision test in proprioceptive condition and visual memory performance (Liutsko, Tous, & Muiños, 2012); imprecision was also negatively related to academic performance and emotional equilibrium (Liutsko, Muiños, & Tous, 2012). Ingram and colleagues reported a significant reduction in motor task performance in the patient with proprioceptive problems. They showed a 60% decrease in results, compared to 10% in control group, when the motor task was switched from single to double (counting numbers backward). This experiment proved the importance of proprioception in cognitive performance, especially when attention needs to be distributed (Ingram, van Donkelaar, Vercher, Gauthier & Miall, 2000). It can be even more challengeable in older people, causing poor balance (Lin & Woollacott, 2005) and irregularity of gait, especially with the cognitive charge (Schellenbach, Lövden, Verrel, Krüger, & Lindenerger, 2010). Research using fMRI has also identified an age-related shift from automatic to more cognitively controlled movements as subjects get older (Heuninckx, Wenderoch, Debaere, Peters, & Swinnen, 2005). It was also found that elderly subjects relied more on visual control in acquiring and performing locomotor task precision (van Hedel & Dietz, 2004).

The majority of studies compare proprioceptive states or age-related acuity in fine motor precision or velocity in different age groups. Goble (2010) results showed the U form of proprioceptive acuity in joint-position matching (30-degree targets) for average absolute errors with higher error in children (8-10 years), followed by the elderly group (70+ years), adolescents (16-18 years) and middle aged (35-50 years), with highest precision in the young adult group (20-30 years). Hurley, Rees, and Newham (1998) reported significant decreased proprioceptive acuity and functional performance in the elder population (mean age 72 years) compared to the young (mean age 23 years) and middle-age (mean age 56 years). Moreover, the older group performed functional tasks significantly slower compared to the rest groups (Hurley, Rees, & Newham, 1998); and less smoothness of movements was reported in senior adults (81.2±1.8 years old) compared to young adults (25.2±2.5 years old) (Yan, 2000).

2.3. Review of sex differences related to proprioception and motor control

Heymans (1911) was one of the investigators who started to study sex/gender differences[1]: he noticed that boys were considered to be more active (difficulty in remaining seated quietly) and with preference for active games, while girls from a grammar school were characterized by quiet behaviour (in the motor, not emotional sense). As for adult women, they were more active in comparison with men, gesticulating more, jumping up from their seats and walking in the apartment. As for the male experts' opinion, men enjoy more frequently than women practising sport (walks, biking, skating, billiards, hunting, etc.), although, female experts considered that men and women enjoyed sports activities at the same level. The most important characteristics of motor behaviour in women differed from men (according to Heymans) in their higher emotionality.

Ananiev (1964) demonstrated higher reaction velocity in men than in women. Ilyin (1978, 1987 and 2002) described prevalence of boys in motor activity and their higher need for movement, but earlier maturation of motor functions in girls. Arkin (1927) in his experimental data about muscular fatigue and tolerance to fatigue in non-heavy tasks (repeated liftings at height of 1 m of a weight of 600 g) found that girls at age of 4-5 y.o. demonstrated less fatigue than boys. Superiority in muscular force (measured by dynamometers) was observed in boys at age of 6.5 years old and was conserved longer. Activation at the beginning was higher in boys, but after 10 repetitions, boys showed symptoms of fatigue and after the 16th trial were not capable of continuing with the task, while the girls were more resistant to fatigue and reached their maximum at the 26th trial. Motor movement maturation happens before sexual maturation: with ages of 12-13 for girls

[1] Sometimes sex and gender concepts are used as interchangeable ones in research articles, however, here these concepts will be considered: sex as biologically determined and gender as culturally determined (Torgrimson & Minson, 2005).

and 13-14 for boys (Ananiev, 1964). In another study by Ananiev (1964), adult women had higher ergographical index (resistance: all the mechanical work done by muscles before fatigue appears is summed). Generally, men were superior where maximum tension was needed, and women did moderate, but prolonged work.

Rose (1970) showed that hand tremor was higher in amplitude and variability in men (from 18 to 28 years old in 1930-60), as well as showing higher asymmetry of tremor. This fact showed that women had greater capacity for fine motor works (assembling clocks, lamps of radios, TVs, etc.). During the charges on the vestibular apparatus, tremors of both hands in young women (16-17) increased by 3-4 times in comparison with young men. Also under intellectual stress (exam), the frequency and amplitude of tremor in women was higher than in men. However, after the exam, the women recovered up to base levels more quickly than men, while values in men continued to increase. The analogical results were obtained for asymmetry of tremor: in men the right asymmetry was quickly changed for left and continued to increase after the exam, while in women the left one increased before the exam, but reduced immediately after the exam. Thus, for any extreme situation (related to vestibular intellectual, as well as emotional loads, as in case of exam) women reacted more strongly than men but they recovered more quickly to basal levels (Rose, 1970).

Investigations by Ilyin (2002) and colleagues resulted in the right hand being stronger than the left for the majority of the population (maybe related to the prevalence of handedness, and this asymmetry is more marked in men. In investigated participants the muscular force first increased (with maximum peaks of 21 years in women and 25 years in men), and thereafter decreased. Moreover the subsequent decrease was smoother in women than in men (in whom sharp ups and downs were observed). Generally, men were stronger than women by 30-40%. In general vestibular charge was shown to have an effect on force, though, sex differences were found in it (boys and girls of 16-17): increasing for the first and declining for the second.

Results of Bagrunov (1981) research (341 men and 268 women) showed that men had prevalence over women in the integration of two psychomotor parameters: velocity and precision, although women had better training effect (psychomotor functions in women were easier to train). Moreover, men were demonstrated to be higher in performance for new sensorimotor tasks, and women in the more stereotyped ones. In general men had greater species variability in a motor area, while women had higher individual variability. Women were more original in their movements and in some situations did not look like their usual selves. Allahverdov (1993) arrived at a similar conclusion: a reflection of everyday views about women as inconstant and unpredictable in comparison to men. Danilova (1998) concluded that men had had more ability for such motor skills as aiming, catching and throwing, while women had been better in tasks where precision and fine hand capacity was needed.

Rose (1970) stressed that graphical movements and dynamic tremor are complex movements that depend on high regulation of the nervous system. Three movement characteristics are present there: force, time and space, and the last had the main importance. Graphical analysis by Rose (MPK of Mira y Lopez) showed that women were more extratensional compared to men since they had biases with direction towards the outside (Rose, 1970). In this study (part lineograms with sample size of thousands of participants, age and sex proportion were not specified) the average line length was established for both sexes: as 36 mm and 38 mm for right and left hands in men; and 37 mm and 39 mm for the corresponding hands in women.

In another study of motor precision of both hands in aiming (Rose, 1970; N=104, age 2-30 years old) there were found alternative periods of prevalence between both sex performances depending on age: before 7 y.o. in favour of boys; from 10 to 18-25 in favor of girls/women. The precision of the left hand was always higher in comparison with men, with the exception of age 20 to 21. In this study the age differences, hand asymmetry and variability was greater in men with sharp changes, while for women these parameters changed more smoothly. Women showed more symmetrical precision in movements for both hands, while men performed more asymmetrically (with dominance for right hand in precision). These findings were congruent with Ananiev's (1968) scheme differentiated for sexes, in which for men there was a need for use of additional adaptive mechanisms (asymmetry) while women passed with basic ones (symmetry).

In general, the differences between performances of men and women are in their specific way of performing: they have different point of centre of mass gravitation and hormone structure; they walk, run, sit down, lift, open tins or close car's doors in a different way. Traditionally, men had prevalence in gross motor performance and women in fine, due to gender roles and the work they were accustomed to carry out more frequently. However, with time, these differences became more insignificant due to emancipation processes in changes in male/female roles in some societies (especially in the western ones). Individual differences, related to sex hormones, were studied more in cognitive tasks. Thus, Kimura (1996) reported that early exposure to sex hormones had lasting effects on problem-solving; and sex hormone fluctuations (in both men and women) were associated with change in cognitive pattern. Women performed better on spatial tests in the menstrual phase of the cycle (low oestrogen) than in the late follicular or midlutheal (high oestrogen). In contrast, their articulatory-verbal and fine manual skills performances were better in the high oestrogen phase. Since men have hormone-related variations related to seasons (in Europe and North

America they have higher testosterone levels in autumn than in spring) on the one hand; and men's spatial ability tends to be better with lower T levels, on the other hand; it was confirmed that men performed spatial tasks better in spring than in autumn. Similar results were obtained at level of daily variability of T levels in men (highest in the early morning) (Kimura, 1996). In studies of cognitive changes via alpha brain rhythms related to phases of menstrual cycle, Muravleva and colleagues (2012) found that in the lutein phase (when prosterogen was at higher levels) both the width of alpha-diapason with related to it the plasticity of solving of cognitive tasks and peaks of individual frequency with related to it fluency of solving cognitive tasks were greater. In contrast, auditory threshold was worse (higher) in lutein and ovulate phases; however this threshold did not change significantly (with less amplitude and almost stable during the whole cycle) in musicians (Kondratenko & Bazanova, 2011). The last fact informs about the plasticity of initial biological or organism differences in favour of plasticity due to certain types of activity (in this case playing piano). Moreover, the same researchers found the sex and age differences in alpha diapason width (related to plasticity) (Fig.2.1), showing the prevalence of male with significant sex differences at ages 3-10; that increased for both sexes until the age of approximately 20 and later started to decline slightly after 40.

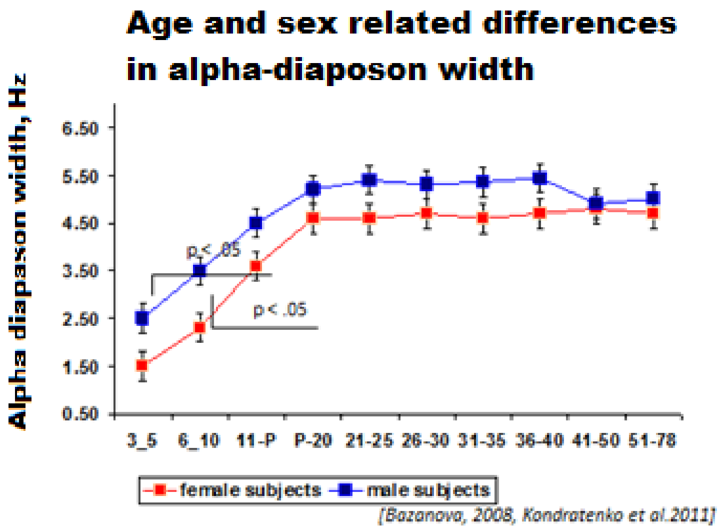


Figure 2.1. Age and sex differences in alpha-diapason width (adapted by Liutsko L., used with permission of author, Dr Bazanova, *source*: Bazanova, Mernaia, & Shtark, 2008; Kondratenko *et al*., 2011).

Revising more results of recent researches, some findings are unclear or even contradictory in relation to sex differences and motor precision, velocity and asymmetry and these parameters were age-related. In both primary school (8-12) and high school students (15-18) girls had prevalence in handwriting short copy task vs. boys, while another longitudinal study (7-11) in copywriting tasks did not reveal any significant sex differences (cited in Dorfberger, Adi-Japha, & Karni, 2009). A male advantage in motor learning rather than in motor performance was found in male adolescents compared to female (Dorfberger, Adi-Japha, & Karni, 2009). The complexity of comparing the results obtained by different studies consisted in not only due to important factor, as shown by the above literature review, such as age, but also due to other aspects, such as type of tasks and sensory conditions used in tests.

Mergl and colleagues (1999) reported slight sex differences in handwriting and drawing kinematic parameters, although men were significantly higher in peak accelerations and wrote with higher mean pressure compared to women. The important conclusion of the results of this study was that men executed less automated writing, implying more intentionality and showing greater variability vs. women (Mergl, Tigges, Schröter, Möller, & Hegerl, 1999). As far as the sensory conditions were concerned, Sigmundson and colleagues found the only significant sex difference in matching tasks to be in favour of women's right hand in the intra-modal matching condition, which success depended on achieving congruency between the visual and proprioceptive spaces in matching hand (Sigmundsson, Haga, & Hopkins, 2007).

Some researchers view the sex-related differences as unclear and relate them more to gender difference posing the question of whether motor performance is to be related to central nervous system rather than to peripheral or to cultural constraints in sex roles reflected in motor activity constraints (Dolfberger, Adi-Japha, & Karni, 2009); while others, such as Piek and colleagues show evidence of limb coordination in infants of 6-18 weeks when gender differences did not have effects as an environmental or social influence, and for this reason should be considered more innate biological factor (Piek, Gasson, Barrett, & Case, 2002). Moreover, studies on animals show clear sex differences that did not depend on social culture. Thus, after induced lesion in substancia nigra (to provoke a situation similar to Parkinson's disease state in humans), female rats had significantly less dopaminergic cell loss and responded with a significantly higher degree of behavioural recovery after the injury compared to male rats (Tamas, Lubics, Szalontay, Lengvari, & Reglodi, 2004). This was evidence of biological sex differences in rats that could be transferred to humans and explain the prevalence of Parkinson's disease in men vs. women. Nevertheless, in another study a small significant prevalence was reported in boys vs. girls (N=427; 44.4% female, ages 9-13) in a rotor pursuit test (in which the participants attempted to keep a small metal disk on the surface of a turntable that rotated at constant speed) (Piper, 2011). However, these results cannot be replicated for other ages and further studies are needed to see all sex and ages interactions.

In tasks of time perception and estimation (related to proprioceptive sense), Espinoza-Fernández and colleagues also found significant sex and age related differences. Their results showed that age was a factor of underproduction of the time intervals, with significant differences for 51 to 60 years and onward (N=140, range 8-70 y.o.) and greater underproduction of longer intervals in women (1 and 5 minutes) (Espinoza-Fernández, Miró, Cano, & Buela-Casal, 2003). Another study carried out by Kring and Gordon (1998) reported the sex as a main effect for sex differences in emotion expression (which is closely related to proprioceptive sense), confirming the previous studies that had labelled women as *externalizers*, or more externally expressive (more verbal communication and face/gesture expressions), compared to men as *internalizers*, having been more psychophysiologically responsive (more electrodermically reactive).

Except on sex and age significant interactions in motor performance, sex and hand use interaction were found also. Thus, in the task to indicate the midpoint of a horizontal line, women showed the left bias to a similar extent with both hands, while men performed the bias predominantly with left hand (Hausmann, Ergun, Yazgan, & Güntükün, 2002). Regarding the higher asymmetry as well as the higher brain lateralization in men, Grabowska and colleagues demonstrated in their longitudinal study with children tested at 5 years old (when they did not know how to read yet) and 7 years old (when they knew how to read) in letter recognition tasks (they had to press the corresponding buttons for stimuli presented in the right and left visual fields) that 7 years old children performed better in the right visual field, while 5 years old ones had similar results in both hemispheres (Grabowska, Herman, Nowicka, Szatkowska,

& Szelag, 1994). The conclusion derived from this study is that hemispheric asymmetry changes occur with age and depend on life experience.

CHAPTER 3. MIRA Y LOPEZ PROPRIOCEPTION LABORATORY (UNIVERSITY OF BARCELONA)

3.1. Antecedents and evolution of methodology within the Mira y López tradition

Из руководимых мною диссертаций на … методе [Mira y Lopez] была основана только одна (из 15) … из-за высокой трудоёмкости методики. Я думаю, что если эту методику удастся изменить таким образом, что будет возможна ***компьютерная обработка****, её распространённость значительно возрастёт.*

Of all the thesis I directed only one (out of 15) was based on the … method of [Mira y Lopez)] … because of the high labour of the technique. I think that if this technique can change the way so as to enable ***computer processing****, its prevalence will increase significantly.*

(Berezin, 2011)

(translation by author)

Working with the Luria's expressive analysis or "detector of lie" (Luria, 1930), Mira y Lopez noticed that amplitude of kinematic movements was different (inhibited persons made them shorter, while the excited ones made them broader, and this did not depend on the context of question). This observation together with Mira y Lopez's previous works (doctoral thesis "*Somatic reactions of mental work*", defended in 1923, and creation of the axiometer working with pilots; Mira y Lopez, 1923) led to his creation of Miokinetic Psychodiagnosis (1958). The main principle of Mira y Lopez was that "*psi-space is not neutral*. *All movements – voluntary and involuntary - performed by man, have a peculiar significance, according to the direction in which they were performed"* (cited in Spanish in Muiños, 2008).

Continuing with the Mira y Lopez thesis, many studies (over 300) were carried out by many scientists and professional in many countries during the second half of the last century (also the majority of works were published in Latin America in Portuguese or Spanish (the list of recovered citations of works is included in Annex 1). From this list it can be seen that many investigations were conducted by Mira y Lopez and his followers within the areas of psychology, pedagogy, medicine and psychiatry, juridical science and professional orientation.

Our Mira y Lopez laboratory in the Personality, Psychological Assessment and Tratments Department (faculty of Psychology, University of Barcelona) made contributions to this area as well, especially in the direction of innovation of the methodology, its digitalization with use of new technologies (Tous, 2008; Tous Ral, Muiños, Tous Lopez, & Tous Rovirosa, 2012), and validation of the initial technique (its quantitative part) (Muiños, 2008) as part of other researches and applicative works. The method's development with use of new technologies is described briefly in Annex 2. Within just over that 10 years of existence, the laboratory investigations (the most recent are reviewed in Annex 3) were represented at national and international conferences, published in national and international journals (the list of the conference participation and published works is in Annex 4), as well the elective course about Proprioceptive diagnostic that was (and is still) taught for students at Master's level at the University of Barcelona.

3.2. Description of DP-TC method

3.2.1. Instruments

To carry out the test the following material is needed:

1. A tactile screen (LGE with resolution of 1280x1024 and optimal frequency of 60 Hz) with a sensory stylus (for hand drawings).
2. A laptop computer (Pentium IV).
3. A specifically designed test software for the recoding and analysis of data.

4. A piece of cardboard (or opaque screen) for the non-vision part of test, to hide the active arm and movement feedback.
5. A stool that can be adjusted to participant height, and a table.
6. Written and oral instructions for correct task procedure and performance (Tous *et al.*, 2012, book in Spanish; Tous, Muiños, Liutsko, & Forrero, 2012, described briefly in article in English).

The computerized test was designed on the basis of its original manual version proposed by Mira (1958) as a myokinetic psychodiagnosis (M.K.P.), improving the precision of the physical measurement of the indicators, reducing experimental mortality with the consequent loss of data and allowing faster administration with fewer errors (Tous *et al.*, 2012; Tous, Viadé, & Muiños, 2007; Muiños, 2008). Moreover the use of a computerized test facilitates its application process; the desire expressed by Prof Berezin (see the epigraph) was accomplished. He did not realize then that a computerized version of some parts of the Mira y Lopez test already existed. In personal correspondence with him (February 2013) he expressed the positive evaluation on video records sent to him about the computerizing of the method and sincere positive surprise at the research work based on the methodology that we conducted in our Mira y Lopez Laboratory (University of Barcelona). Unfortunately, in spite of internalisation processes and the common use of English in scientific research, there still exist a great gap in dissernisation of knowledge, especially of the work (much of it of great significance) that had been done in the past century, when the linguistic barriers were more substantial. In order to understand the methodology, a brief description is given below.

3.2.2. Procedure

The precision of fine motor performance (hand drawings over model lines) was measured in the following directions (as shown in Fig. 3.1):

1) Transversal movements in an interior to exterior direction (horizontal lines in the horizontal position of the screen).
2) Sagittal movements from inner to outer direction (vertical lines in the horizontal position of the screen);
3) Frontal movements from lower to upper direction (vertical lines in the vertical position of the screen).

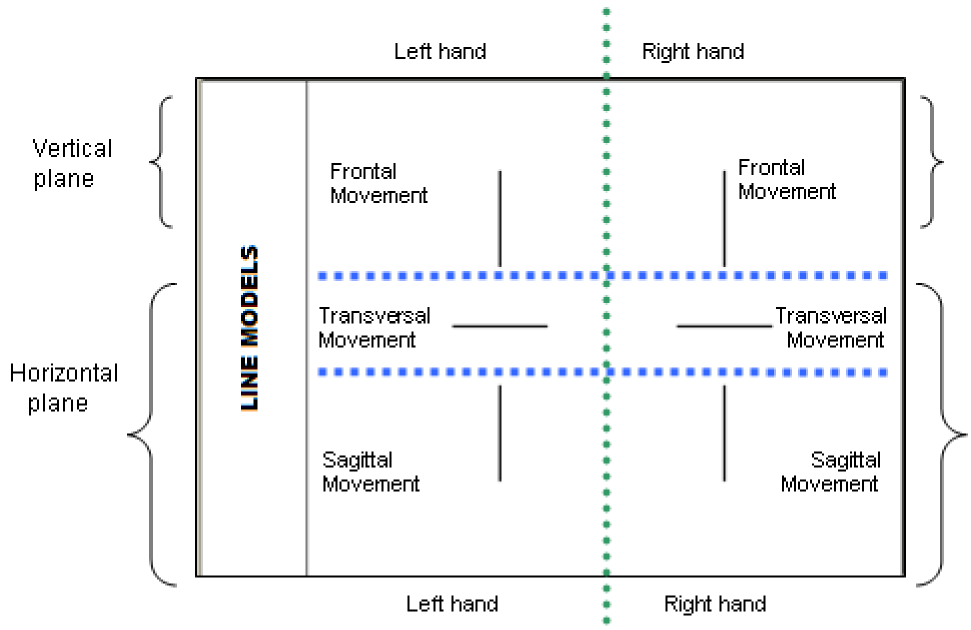


Figure 3.1. Representation of DP-TC test task involving tracing over the line model: six lines measuring hand movements in three directions (transversal, sagittal and frontal) for both hands (right and left) (translated and adapted from Muiños, 2008).

Generally there are two main types of stimuli (models to follow) in DP-TC test:

a) Lines of 40 mm length (or lineograms) (see Fig. 3.1.) for all movement types and both hands, and
b) Parallels, lines to be drawn inside of the models, represented in from of ∏ or inverted ∏ (see Fig. 3.3 and 3.4) with width of 50 mm and height of 158 mm, with distance between them of 8 mm.

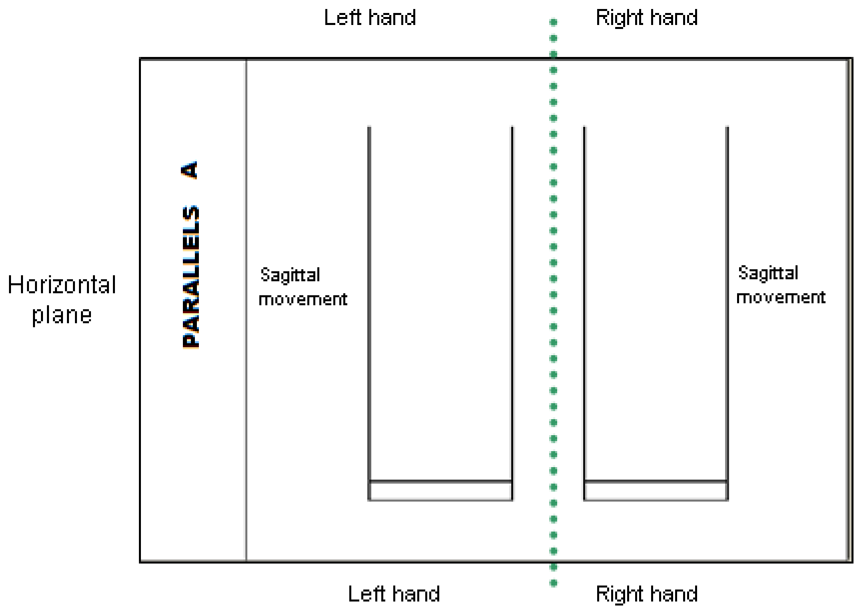


Figure 3.2. Ascendent parallels in the DP-TC test (translated and adapted from Muiños, 2008).

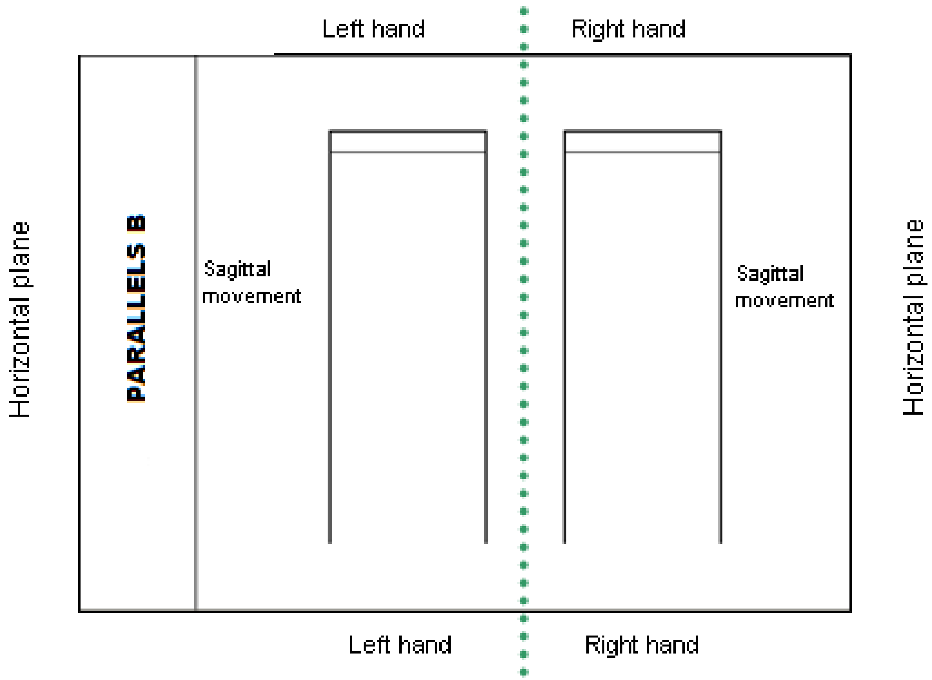


Figure 3.3. Descendent parallels in the DP-TC test (translated and adapted from Muiños, 2008).

In lineograms, all tasks for each movement direction (F- frontal, T – transversal and S – sagittal) were performed within 13 trials: the first three were obtained with vision and the following ten without vision. In parallels (ascendents and descendents), the first two lines are traced over model, the next three lines continue to be drawn in vision condition by participant calculating the distance between them as it was initially, and then the proprioceptive part starts (without interruptions), and the participant continue to draw parallel lines without seeing feedback of drawing model or his active arm until he arrives in the marked by DP-TC program line.

3.2.3. General test condition instructions

In order to obtain reliable data, the correct posture is required, and stool and table heights have to be adjusted individually to allow free elbow movement. The following points should be checked before and during the task performance for both parts of test (with and without vision): body in the upright position looking straight ahead (without leaning to the left or right during the graphical performance of the movements) with the feet together on the floor. Participants should be seated comfortably without having to bend the back or extend the arms in an unnatural way.

The hand not being used in the task should be resting on the leg ipsilateral to it. The hand and arm used for the task should have no tactile contact with anything (except the stylus with which the drawing is performed), while the wrist must be kept rigid, a stylus should be held in the middle by the thumb, ring and index fingers, as when painting (see pictures taken during the test: Fig. 3.4, 3.5 and 3.6).

Finally, the main environmental issues that could have an influence on the test result were taken into account: a silent laboratory with a comfortable temperature; a pre-test instruction not to consume any substances (coffee, drugs, etc.) that might affect fine motor activity, and the posture with the least tension for the upper limb movements.

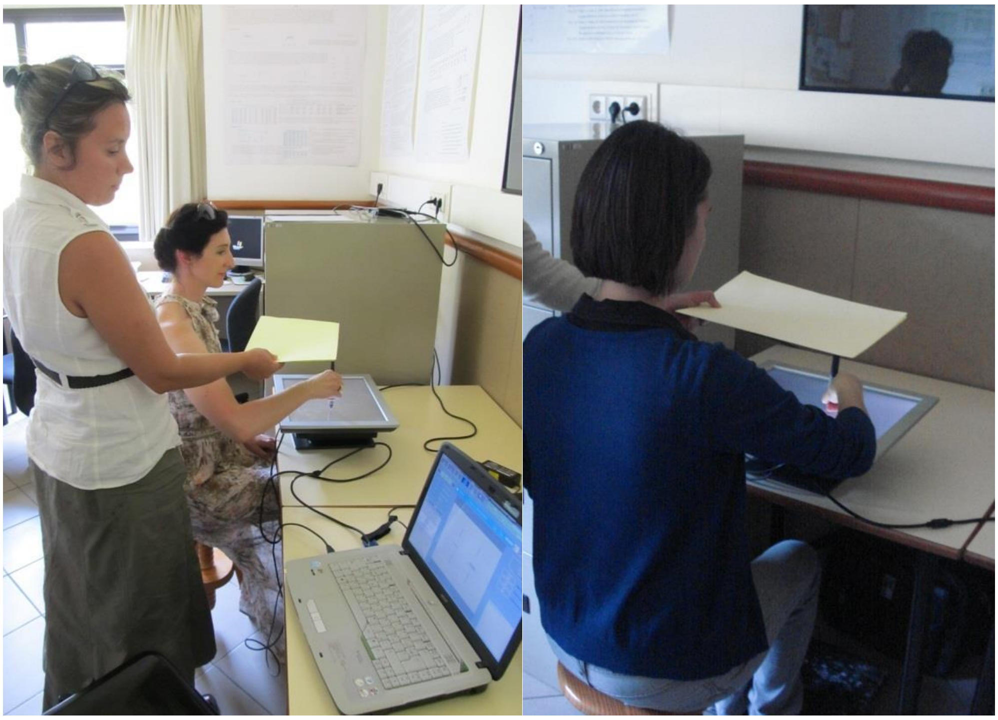


Figure 3.4. DP-TC test (right hand, transversal movement type in proprioceptive sensory condition).

Plate authors: Plotka, A. (used with permission) and Luitsko, L.

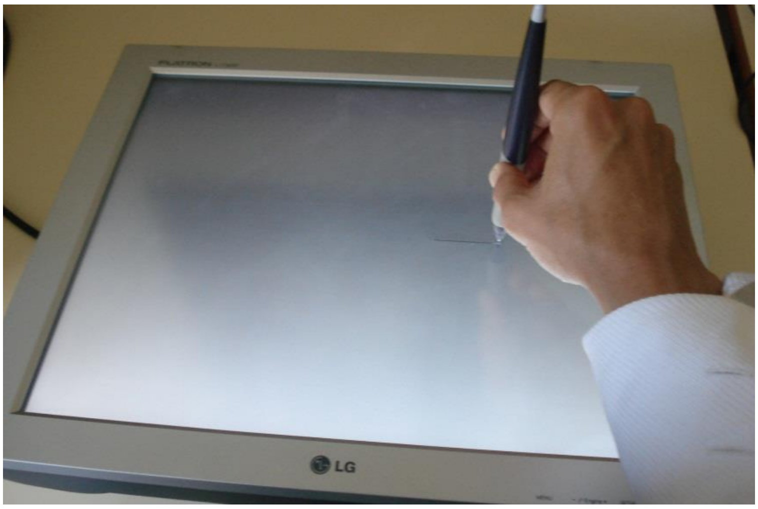


Figure 3.5. (*Plate by author*) Performing the line tracking over the model (right hand, transversal movement type, visual sensory condition).

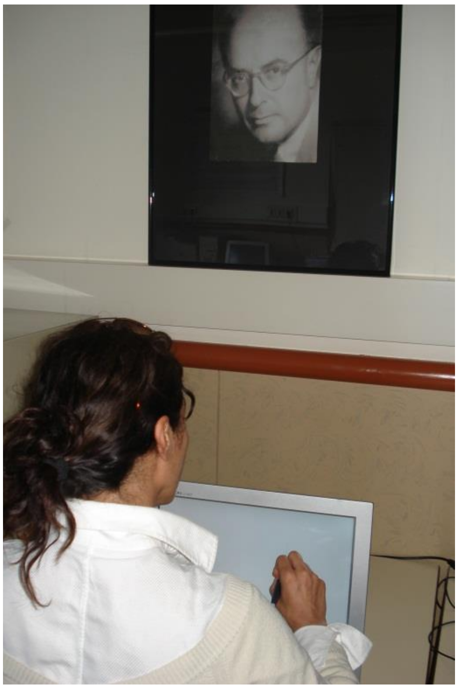


Figure 3.6. (*Plate by author*) Performing the DP-TC test: right hand, frontal movement type, visual sensory condition. Place: Mira y Lopez Laboratory (department of Personality Assessment and Treatment, Faculty of Psychology, University of Barcelona) with a photo of Mira y Lopez on the wall.

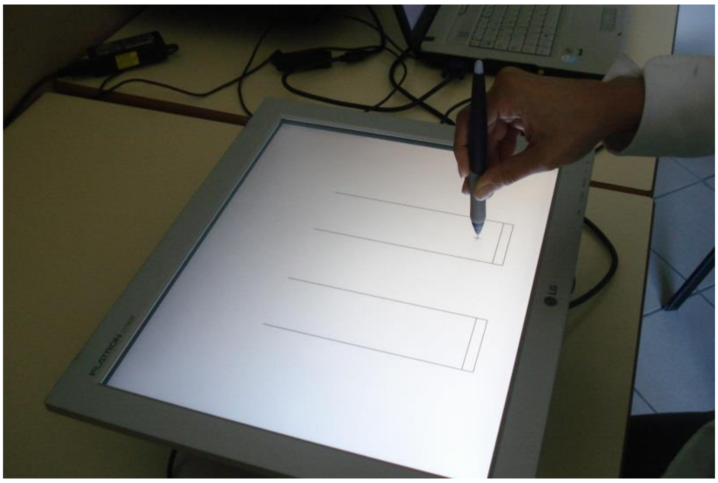


Figure 3.7. (*Plate by author*) Before performing the DP-TC test: stimuli – parallels; right hand, transversal movement type, visual sensory condition.

3.2.4. Specific instructions for performing DP-TC test

a) Lines (o lineograms):

"You are requested to trace over the model line from the starting point to the end of it; then trace backward (returning) to the starting point without interruption. Repeat these movements, trying to reproduce the model line as accurately as possible. At first you will be able to see the model line, but after some trials a piece of cardboard will be placed between you and the screen. You will not see your hand position or the line model but you will have to continue drawing the lines as before without stopping. During of each section of reproduction do not lift your stylus until the end of the task." These instructions were used in the task for all six lineograms' segments representing the three measured directions for each hand.

b) Parallels:

"You have to track first visible lines, from the internal to their external end, lifting the stylus at the end of each line. You have to follow drawing of parallel lines up/down (depending if there are ascendent or descendent, see Fig. 3.2 and 3.3), preserving their length and distance between them as initially drawn (or traced). After several trials with vision, you will not be able to see the model feedback or your active hand; however, you have to continue until the signal or command given to stop".

c) General instruction to start: "Point with a stylus to the dot you see at the beginning of the model, and when you are at the correct start position (for everyone it is the same point), the marking of line colour will be changed from red to green. At the moment, please do not move your hand or lift it; I will press the recording data button and give you a signal to start tracing."

3.2.5. All observable variables

3.2.5.1 Quantitative variables (displacements compared to model or within a single participant's movements)

There are three main types of this type of variables:

a) spatial errors, b) changes in line length, and c) fluctuations in line length (or difference between maximum and minimum line length performance. The spatial and line length errors (Fig. 3.8) are obtained from the lineograms, while fluctuations in line length (Fig. 3.9) are measured from the parallels.

The spatial errors are divided in their turn into subtypes:

- directional (parallel to the movement direction), and
- formal (perpendicular to the movement direction).

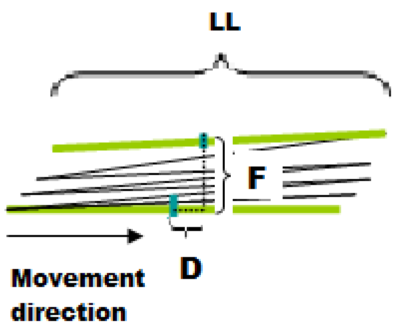


Figure 3.8. Representation of directional (D) and formal (F) biases measurement: from the middle of the measured line the perpendicular is drawn to the base line that was the formal deviation (F); and the distance from this point to the middle of the base line was the directional deviation (D). LL is line length.

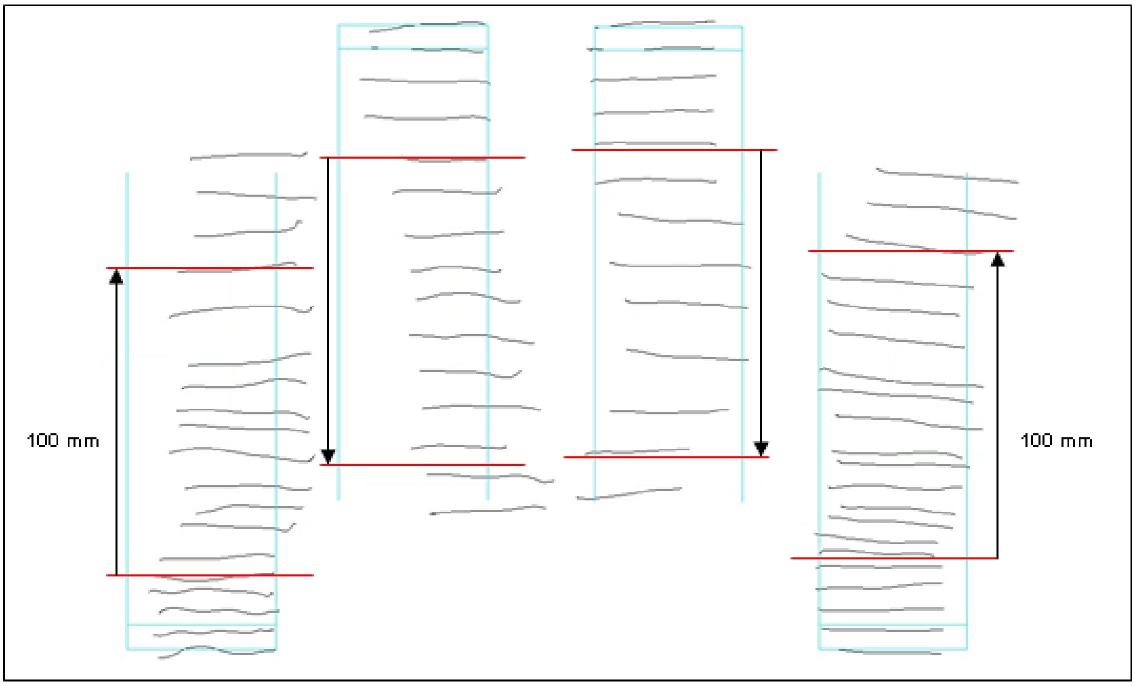


Figure 3.9. LL fluctuations or variability measurement in DP-TC test (proprioceptive sensory condition only) (adapted from Muiños, 2008).

3.2.5.2. Qualitative analysis of performance

This is the only part not digitalised yet in the current version of DP-TC; however, some part can be done in the future or just by video filming being substituted during the test (general picture of the participant and detailed picture of his tracings). At the same time, the instructor can observe and make notes about both changes in posture of participant and qualitative image during the performance that can be especially important in cases of pathology or intoxication. As per Mira (1958), if the lines deviate by more than 15º from the initial model, such cases should be considered as “abnormal”, and the participant might have some kind of pathology of neurological basis.

3.2.5.3. Examples of abnormal graphical performance during DP-TC test (taken from own practice in Belarus, 2012)

1) Participant A (male, 31 years old) has diagnosis of multiple sclerosis and had a fall from a high tree at age 18 (from personal interview). DP-TC test qualitatively (and related to it psychological profile) showed only one parameter that was at the "border" of normality- pathology, having a standardized T-mark of 80 (when T-range from 40 to 60 describes 67% of population): it was fluctuation in behaviour, or Impulsivity scale and in Irritability scale. He had T=80 for these scales for both (dominant and non-dominant) hands. The deviations for the rest of scales were those of the majority of people, quite normal ones, with a slightly high tendency to optimism in the Mood scale (Fig. 2.11 to see his psychological skeleton). However, the qualitative analysis of his DP-TC performance had shown the "rareness" in two cases:

- First, in the lineograms of frontal movement type of left hand (right hemisphere) in the proprioceptive sensory condition the linearity of lines was disrupted: he drew non-linear forms, curves; sometimes they were similar to number eight.
- The second and stronger indicator was when he drew intersected lines in the part of the test where they should be parallel.

2) Participant B (female, 13 years old). This was the second and the last person from this group (114 participants) observed to perform the same curve drawings instead of lines in the lineograms (and they both took the DP-TC test with some days of difference). The most surprising thing was a remarkable similarity of drawing curves, and it was repeated for the same hand and movement type (frontal

movement, left hand). The girl had no observed behaviour similar to multiple sclerosis (this disease is developed and diagnosed later, from 20 years old usually) and she conserved the line parallel in another part of the test; however, she demonstrated a difficulty of upright posture throughout the whole test (15-20 minutes). As for the quantitative and psychological skeleton, she showed a similarity to Participant 1 in her temperamental tendency to optimism and clear temperamental tendency to Irritability. As concerned Impulsivity scales, their scores were actually identical, T=80 (frontier to pathology cases) for both hands (Fig. 3.10 and 3.11 for the psychological skeleton image). Another distinct indicator of her DP-TC profile that was as high as the Impulsivity scale was Emotivism for non-dominant hand, showing temperamental predispositions, though stabilized by her character within norms. Maybe both a high capacity to natural Emotivism together with high Impulsivity explains that she attends art school and she is an original and unusual artist (in drawing and painting). Nevertheless, one thing in drawing the line by left hand in frontal movement was very similar to the Participant 1. What could it be? During the interview with her mother, I asked if she remembered her daughter falling from high place in her biography. And the answer was affirmative: when she was 3 years old, she was pulled down by a boy as they played together on stacked construction materials; however, the height was not as great as an average tree.

To sum up, the DP-TC qualitative analysis is important for detecting some neurological disturbances. Further studies are required to confirm the hypotheses arising from these practical individual observations:

- whether intersections of lines instead of parallel ones occur in all (or the majority) of patients with multiple sclerosis; and

- whether non-linear representation of lineograms of left (non-dominant) hand in the frontal movement type and proprioceptive sensory condition of DP-TC test can help detect other neurological problems related to significant falls.

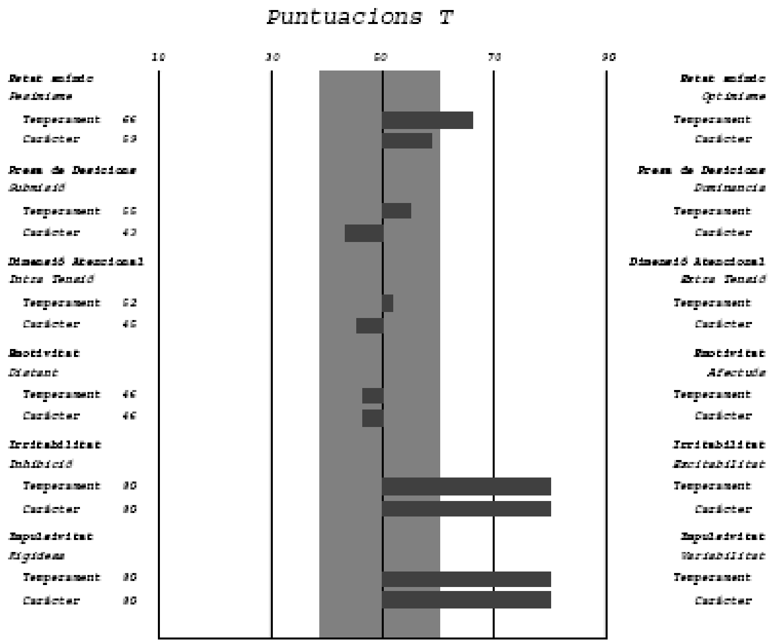


Figure 3.10. The psychological profile with T-scores of Participant 1 (male, 31 y.o.).

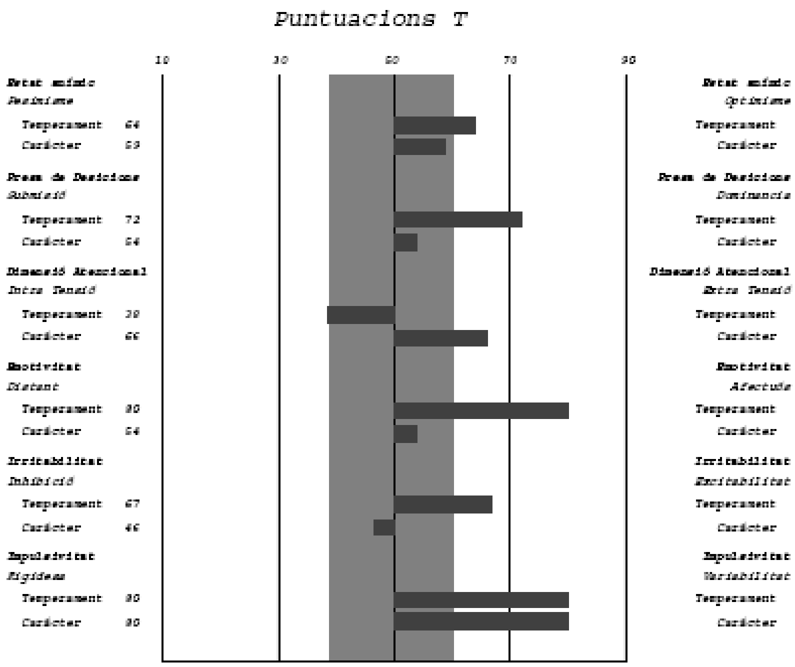


Figure 3.11. The psychological profile with T-scores of Participant 2 (girl, 13 y.o).

3.2.5.4 Psychological profile (derived from the quantitative analysis)

In the studies carried out to develop the Proprioceptive Diagnosis of Temperament and Character (DP–TC abbreviation from Spanish) test the exploratory factor analysis (Tous, Viadé, & Muiños, 2007) and the subsequent confirmatory factor analysis (Muiños, 2008) showed that the instrument had six orthogonal bipolar factors:

1) *Mood* (from pessimism to optimism, with depression and mania at the poles);
2) *Decision-Making* (from submission to dominance, with inward and outward aggressiveness at the poles);
3) *Attention Style: Intra-tension and extra-Tension* (from inward to outward, with high self-absorption and high distraction for external stimuli at the poles);
4) *Emotivism* (from cold/distant to empathy/affiliation);
5) *Irritability* (from behavioural inhibition to behavioural excitability);
6) *Variability* (from rigidness to variability/flexibility in behaviour).

These factors are different from those that can be obtained on verbal tests since they correspond to how a person really behaves, rather than to what he/she thinks about his/her behaviour. As Kagan (2005) argues, if our goal is to make reliable predictions about behaviour and to intervene effectively in it, it is more important to know how a person behaves than it is to know what that person thinks about him or herself. Moreover, as Shibutani (cited in Miroshnikov, 1963) said, “the person should be determined in terms of his/her potential activity, and not those seen by others”. Real behavioural trends can be repressed. And these hidden internal behavioural trends are reflected in motor function (Luria, 1932). Miroshnikov (1963) described in his scientific literature review the psychological reactions that lead or were related to specific motor actions:

- *increasing of movement amplitude* could be a way of expressing signs of anxiety, fear, anger, happiness, exaltation or other psychomotor excitability caused by various sources, including the pharmacological one;
- motor control deteriorated by fatigue, worsen both concentration of attention and function of the sensorimotor coordination mechanisms;
- *decreasing of volume (or amplitude) of movement* was related to deterioration of motor control with increased inhibitory impulses that led to rigidity of movements and were observed in any asthenic states related to depression and high anxiety;
- *temp*: conservation or stability (especially when changes in environment occur) were related to stability of conative force;
- increasing of *muscular tonus*: as a reactive protection in situations of anxiety, fear, insecurity and timidity when the person creates intrapsychic tension; this "demobilization" reflected in muscular hypertonia can provoke depletion of emotional-conative sphere, passivity and depression;
- *movements in vertical plane:* dropping hands and changing the posture due to gravity force reflected loss of psychomotor tonus; thus movements directed down here denoted fatigue, unwillingness to fight or apply force, depression; on the contrary, an upright body position and capacity to handle extremities at the same level meant activity and vitality. When the person felt psychomotor excitation (strong fear, anger and happiness), he/she had a tendency to move hands up;
- *movements in vertical plane:* active interest in any subject/object in the visual field was related with movement towards that subject/object; however, there was the case of thehighest reaction in this movement when the person had strong emotions and drives to remove the source of danger or barrier (aggressive behaviour); on the other

hand, a passive reaction to it or a wish to be hidden or culpability provoked movements "inside" (introjective aggression);

- *movements in horizontal plane:* movements tending outwards were related to exteriorization and more social contact, while movements inwards were related with submerging into the internal world (interiorization);
- *motor disorganization*: visual or latent chaotic distribution of muscular tonus were related to behavioural disorders (mainly due to affective causes when the perception was changed and kinaesthetic control affected); here also can be observed the "psychological blockade": paralysation of movement with high muscular tonus.

The experimental work with use of myokinetic method was also used to study individual differences in frustration (MacKinnon & Henle, 1948) and interhemispheral motor asymmetry in patients with schizophrenia and neurosis (Efremov, Sluchaevskii, Popov, Rozenfel'd, & Dunaevskaia, 1982) and in health participants to study their tolerance of and adaptation to environmental changes (Berezin, 2011; Ezhov & Krivoshchekov, 2004; Draganova, 2007). This psychomotor method was reported to be informative in behavioural changes to stress there.

Thus the proprioceptive methodology can be also used for measuring of individual profiles based on their neurological and physiological characteristics that are reflected in psychological and behavioural types. However, this thesis work is more focused on description and analysis of individual sex and age differences of fine motor kinematics of hands. The main interest lies in observing how fine motor behaviour (precision and velocity) is changed in proprioceptive sensory test condition when the behaviour cannot be rectified by other exteroceptive inputs, primarily by vision and touch. Then it is more intrinsic and characterizes the inherent individual qualities as basic ones or tendencies to some behavioural types that are natural or to be more easily executed since they work on an automatic level and are “saved” in muscle tensions and joints and in proportional work of the antagonistic muscles as more regular ones (a custom). However, it is also possible to see the evolution or reactive maladaptation to environmental stress by analysing the manual symmetry/asymmetry of performance. The graphical application of the test is one of the major strengths of the method, allowing comparison of individual differences of persons from different cultures and language, as was done, for example, in the 1970s studies of Berezin and colleagues to check stress adaptation in indigenous and migrant populations of Nord- East Extreme regions of Russia (Berezin, Varric, & Gorelova, 1976).

CHAPTER 4. AGE AND SEX DIFFERENCES IN PROPRIOCEPTION BASED ON FINE MOTOR PERFORMANCE

4.1. Methodology and data analysis

4.1.1. Participants

The sample was comprised of participants with normal or corrected-to-normal vision (N=196, age=33±21 years, range: 12–95, men: 75%). Participants were self-reported as healthy people who were not undergoing any medical treatments. Handedness was checked by means of the Lateral Preference Inventory (LPI; Coren, 1993), which revealed right-hand dominance in 95% of subjects. Individuals who had been forced to change their hand dominance at school were excluded from the study. All subjects took part voluntarily, were informed about the aims of the research and gave their consent prior to inclusion in the study. All tests were administered in line with ethical guidelines on human research.

4.1.2. Instructions

In this study the instructions were used as for the linegrams (described in the Chapter 3.3.4). The starting point was the same for all participants, as once the subject had set the stylus at the correct coordinates, the line changed colour from red to green. The researcher only started to register the data once the line was green.

4.1.3. Procedure

Fine motor behaviour, which was assessed by the precision of line lengths together with spatial deviations (tracing over 40 mm model lines) and task speed, was measured in frontal, transverse and sagittal directions for both hands and under two test conditions: proprioceptive information only (P) and proprioceptive + visual information (PV). Correct posture (body in the upright position looking straight ahead without leaning to the left or right during the performance of movements, and with the feet together on the floor) was ensured in all subjects, and stool and table heights were adjusted individually to allow free elbow movement. This meant that subjects were seated comfortably without having to bend their back or extend their arms in an unnatural way. The hand/arm used for the task was only in contact with the stylus with which the drawing was made, and the wrist was kept rigid. The hand that was not being used in the task rested on the ipsilateral leg. Subjects held the stylus in the middle using their thumb, ring and index fingers, as when painting. The software recorded data on size (LL), spatial deviations (D - directional and F - formal) and performance speed for each participant under both test conditions (P and PV). The deviations from the model were transformed from pixels into millimetres. Instruments that were used in study are described in the lineograms part in Chapter 3.3.

4.1.4. Data analysis

All analyses were done using SSPS v.19. The descriptive statistics were performed for fine motor performance, precision (LL, D and F) and speed (T), in both sexes and four age groups in various combinations of test conditions: MT – movement type (Frontal, Transversal and Sagittal), hands (ND – non-dominant and D – dominant) and sensory conditions (PV – proprioceptive-visual, and P – proprioceptive-only). MANOVA analysis with Bonferroni correction for multiple comparison was performed to check the significant effects of sex, age and sex*age interactions. For MANOVA and correlational (hand symmetry) analysis, data were split into four age groups (12–17; 18–29; 30–64 and 65–95) that corresponded to adolescent /secondary school), early middle (higher-level studies or starting professional), middle (professional work) and old (related to retirement) periods. The time spent was also measured on the whole task and on each test condition (PV and P), thereby enabling us to calculate the average speed for the complete movement (forward/back or up/down) in both directions and with both hands.

To see whether there existed a difference in performance between either hands (D vs. ND) or two sensory test conditions (PV vs. P), the corresponding paired analysis was performed. In addition, the study of symmetry and asymmetry between both hands performances in both sex subgroups were performed and analysed in the light of age-dependent differences also (paired differences of Wilcoxon sign test). Additionally, the corresponding correlational analysis was conducted to find the relationship between non-dominant and dominant hand performances. The data were calculated to four age subgroups in order to see how hand symmetry/asymmetry changed depending on age and sex. Moroever, how the proprioceptive biases trends in size and spatial deviations and absolute precision depended on the speed performance in different test conditions were analysed (correlational analysis) to see whether any significant relationship existed and whether it was of positive or negative sign.

Regression analysis for age-dependent behaviour was performed in order to see the proprioceptive fine motor behaviour function both for precision and speed for the whole data (age range 12-95) as curvilinear analysis (fit for quadratic function as it was set in the hypothesis). Curvilinear regression analyses (second-degree polynomials) were performed with the precision and task speed data to estimate the model that best fit the data, as well as to determine the inflection points for those observable variables where the quadratic function regression model was significant, so as to identify the approximate age corresponding to optimal motor precision under both test conditions and for both hands.

4.2. Results

4.2.1. Age and sex differences in fine motor precision and speed

Precision in fine motor precision was measured under different test conditions, three movement types (F – frontal, T – transversal and S – sagittal), both hands (ND – non-dominant and D – dominant) and two sensory conditions (PV and P), as three observable variables (LL – line length, D – directional bias and F – formal bias) in men and women and different age groups. Thus, the complete model was described by three variables of precision or deviations (LL –line length, D – directional bias and F – formal bias) and speed (T - time) that depend on three factors of test conditions (MT – movement type, SC – sensory condition and Hand) and two factors of study – age (age group) and sex:

Precision (LL, D and F)
Speed (T)
} (MT + SC + Hand) + Age+ Sex

or restructured, as the following one:

Precision (LL, D and F)
Speed (T)
} test conditions (MT + SC + Hand) } Age+ Sex

The preliminary MANOVA test revealed that test factors, such as movement type (MT) and sensory condition (SC), were significant for all observable variables: LL, D, F (p<.001) and T (p=.024 for MT and p<.001 for SC); Hand was significant for LL (p=.022) and T (p=.028). As for the factors of study (Age-group and Sex) Age-group was significant for LL and T (p=.001) and Sex for D (p=.04) and T (p=.001), although other iteractive combinations of three factors of test conditions and two factors of study were significant also.

For this reason, as well as in order to show the tendencies of fine motor behaviour as a complete picture, the study analysis and results were performed for four observable variables (LL, D, F and T) in three test conditions (MT, SC and Hand) for two factors of the interest of study: Age and Sex. This information contributes to the global view of results, although the differences reaching statistically significant level will be emphasised separately. The general descriptive statistics of the observable variables - LL, D, F and T is represented in Tables 1-4 below.

Table 1. Descriptive statistics age * sex differences in size precision (LL bias) (in mm)

			sex	Male		Female	
MT	Hand	SC	age_group	*M*	*SD*	*M*	*SD*
Frontal	ND	PV	12-17	42.90	3.59	42.00	3.34
			18-29	40.90	2.78	41.83	4.14
			30-64	41.77	3.01	38.67	2.97
			65-95	37.38	4.25	34.86	3.13
		P	12-17	40.71	9.18	34.83	6.91
			18-29	40.28	12.48	40.53	11.88
			30-64	40.20	8.98	38.88	12.96
			65-95	65.64	36.93	48.29	14.75
	D	PV	12-17	41.70	2.71	39.70	2.62
			18-29	39.27	2.40	40.61	3.99
			30-64	40.96	2.06	37.44	2.78
			65-95	34.33	3.41	34.46	4.11
		P	12-17	41.11	14.03	35.73	6.83
			18-29	39.04	9.76	39.41	10.84
			30-64	40.12	7.28	38.72	10.62
			65-95	60.96	35.68	49.51	18.43
Transversal	ND	PV	12-17	55.64	5.42	55.37	4.90
			18-29	32.92	3.87	34.41	4.01
			30-64	37.02	3.02	46.96	12.57
			65-95	49.91	8.24	53.03	5.64
		P	12-17	51.64	17.00	49.40	27.84
			18-29	30.18	7.17	30.78	6.60
			30-64	34.63	7.24	46.74	21.20
			65-95	96.91	70.55	77.91	38.78
	D	PV	12-17	53.33	2.09	51.73	7.61
			18-29	32.92	2.19	33.36	3.77
			30-64	36.01	3.78	47.17	8.35
			65-95	44.01	15.75	49.23	5.22
		P	12-17	44.61	15.50	38.63	11.34
			18-29	29.38	8.81	29.04	8.48
			30-64	32.94	8.80	43.25	14.66
			65-95	83.84	44.75	88.11	40.39

Sagittal	ND	PV	12-17	39.73	4.09	38.87	2.18
			18-29	37.90	2.99	38.93	4.40
			30-64	37.50	3.88	35.71	2.14
			65-95	33.09	3.36	32.74	3.01
		P	12-17	35.90	8.84	28.63	5.44
			18-29	32.88	7.64	33.80	9.15
			30-64	35.90	7.83	32.80	8.90
			65-95	50.30	27.98	48.43	17.34
	D	PV	12-17	38.74	3.83	39.13	1.94
			18-29	38.19	2.43	38.93	3.50
			30-64	37.48	4.61	37.13	3.66
			65-95	33.11	3.43	33.46	3.17
		P	12-17	36.19	27.09	25.53	3.28
			18-29	31.93	9.01	33.68	8.97
			30-64	35.06	7.33	32.51	9.96
			65-95	51.13	23.21	47.94	18.83

Legend: ND – non-dominant (hand), D – dominant (hand), P – proprioceptive-only and PV-proprioceptive-visual; SC - sensory condition, MT – movement type.

Table 1 represents descriptive statistics for LL precision performance (in mm) for both sexes agroupped in four age subgroups: 1) 12-17; 2) 18-29; 3) 30-64 and 4) 65-95. Line length performance changes through the different age groups, being greater both in mean value (*M*) and variability (*SD*) in the eldest age subgroup. As per DP-TC test, LL in P test condition reflects the balance between inhibition and excitability, thus showing more balanced performance (compared to the model line length of 40 mm) in the young and middle age groups with more tendency to inhibition in the middle ages (18-29 and 30-64) and higher excitability in the eldest group in both sexes (except on performance in ND hand and frontal movement). In some movements (P-test and eldest group), men overperformed women in LL. For example, the greater differences were observed in transversal movement and ND hand (96.91±70.55 mm vs. 77.91±38.78 mm) and in frontal movement in both hands (ND: 65.64±36.93 mm vs. 48.29±14.75 mm and D: 60.96±35.68 vs. 49.51±18.43 mm).

In PV-condition, in frontal movement in the eldest group the inhibition (underperforming of line length) was more pronounced in both hands; although in P-test the contrary situation of higher excitability (overperforming of line length) was observed.

Table 2. Descriptive statistics age * sex differences in spatial precision (D bias) (in mm)

			sex	Male		Female	
MT	**Hand**	**SC**	**age_group**	***M***	***SD***	***M***	***SD***
Frontal	ND	PV	12-17	-0.86	4.53	-1.03	2.85
			18-29	-1.26	1.57	-0.71	1.80
			30-64	-1.01	1.56	-0.47	1.17
			65-95	-1.95	1.93	-0.54	1.46
		P	12-17	-6.01	18.11	-11.57	14.07
			18-29	-4.12	11.66	-8.55	12.72
			30-64	-0.13	10.60	-2.85	6.87
			65-95	-7.29	18.53	4.57	15.08
	D	PV	12-17	-0.73	2.36	-0.43	2.04
			18-29	-0.58	1.12	-0.25	0.73
			30-64	-0.50	0.94	0.01	1.40
			65-95	-1.48	2.69	-0.57	1.60
		P	12-17	-14.12	16.51	-11.70	13.44
			18-29	-11.49	14.32	-9.26	10.97
			30-64	-7.22	12.16	-7.96	6.94
			65-95	-15.20	16.39	-5.00	25.38
Transversal	ND	PV	12-17	-0.19	4.08	-0.20	1.02
			18-29	-0.24	2.14	-0.44	1.98
			30-64	-0.17	1.12	-0.26	3.09
			65-95	-2.23	3.70	-0.69	3.76
		P	12-17	2.94	21.33	10.77	20.79
			18-29	-1.67	10.72	-1.37	11.57
			30-64	0.24	12.85	-0.15	37.95
			65-95	-16.99	47.14	9.60	29.62
	D	PV	12-17	-0.26	4.19	0.20	2.79
			18-29	0.17	1.39	-0.44	1.30
			30-64	0.18	1.36	0.23	2.40
			65-95	2.22	14.24	0.57	2.37
		P	12-17	-3.13	15.11	2.03	16.39
			18-29	-1.06	10.45	5.69	14.17
			30-64	2.94	11.08	2.04	21.98
			65-95	-8.57	28.37	-22.94	31.33
Sagital	ND	PV	12-17	-0.55	2.21	-0.80	2.18
			18-29	-0.07	2.09	-0.67	1.55
			30-64	1.51	1.84	0.64	2.69
			65-95	-0.42	1.69	-0.83	2.36
		P	12-17	12.53	12.08	13.67	10.31
			18-29	15.33	11.48	14.79	11.99
			30-64	14.34	11.46	11.34	11.46
			65-95	11.30	16.30	17.34	26.46
	D	PV	12-17	0.21	2.07	-0.17	0.99
			18-29	0.02	1.85	-0.04	1.74
			30-64	1.39	2.44	-0.13	1.16
			65-95	-0.75	1.25	0.55	-0.45
		P	12-17	19.30	25.15	15.83	9.95
			18-29	15.70	10.72	16.58	12.32
			30-64	14.10	11.00	13.54	11.78
			65-95	8.76	13.65	20.80	22.72

Legend: ND – non-dominant (hand), D – dominant (hand), P – proprioceptive-only and PV-proprioceptive-visual; SC - sensory condition, MT – movement type.

As far as directional bias in precision performance is concerned, in P-test the common tendency for the majority of variables was a change from greater imprecision (and variability in performance) in the youngest group (12-17) to the minimum error in middle ages and increased error in the eldest group. In frontal movement and ND hand (P-test), women had a slightly higher tendency towards depression compared to men in the first three age subgroups, while the situation was controversial in the eldest age. In D hand, although in the eldest group a similar tendency was observed in sex difference performances, in the first three age subgroups the values were substantially the same in both sexes (Table 2).

In transversal movement and ND hand (P-test), women outperformed men in mean value in age 12-17 (10.77±20.79 mm vs. 2.94±21.33 mm), showing higher tendency towards temperamental Extra-tension. In the middle ages, the performance was quite equial in both sexes and with less error, indicating for the balance between both poles in Attention style dimension (Intra-tension and Extra-tension). In the eldest group, while women had similar values to the age of 12-17 with tendency towards Extra-tension, men changed their movements, as an average value of group, towards a higher Intra-tension (-16.99±47.14 mm in men compared to 9.60±29.62 mm in women). In D hand of the same movement, the women performance in the eldest group had a greater tendency towards Intra-tension compared to men (-22.94±31.33 mm vs. -8.57±28.37 mm).

In sagittal movement, and for both hands (P-test), women showed greater error than men in the old age group (65-95) with tendency toward higher dominance (ND hand: 17.34±26.46 mm vs. 11.30±16.30 mm; D hand: 20.80±22.72 mm vs. 8.76±13.65 mm), whereas men showed a slight dominance compared to women only in the youngest group for D hand (19.30±25.15 mm in men vs. 15.83±9.95 mm in women).

Table 3. Descriptive statistics age * sex differences in spatial precision (F bias) (in mm)

			sex	Male		Female	
MT	Hand	SC	age_group	*M*	*SD*	*M*	*SD*
Frontal	ND	PV	12-17	0.17	1.35	-0.33	1.59
			18-29	0.09	0.90	-0.23	0.83
			30-64	0.23	0.88	-0.41	1.26
			65-95	1.50	1.32	0.94	1.49
		P	12-17	13.26	10.09	11.93	9.01
			18-29	9.83	8.81	9.41	4.91
			30-64	10.41	8.72	16.74	14.96
			65-95	27.96	34.64	26.29	25.71
	D	PV	12-17	-0.57	1.23	-0.17	1.07
			18-29	-0.13	0.52	0.08	0.56
			30-64	-0.03	0.62	0.37	0.80
			65-95	0.56	1.55	-0.26	1.69
		P	12-17	17.05	17.55	14.20	11.26
			18-29	9.65	7.57	10.55	7.06
			30-64	8.15	6.61	10.06	8.57
			65-95	22.91	25.65	37.54	29.21
Transversal	ND	PV	12-17	-0.50	0.56	-0.27	0.39
			18-29	-0.36	0.76	-0.46	1.22
			30-64	-0.37	0.81	-0.55	0.57
			65-95	-0.23	0.80	-1.20	2.27
		P	12-17	-4.65	7.09	5.77	25.27
			18-29	-0.98	7.39	-0.71	8.26
			30-64	-3.45	9.14	-2.71	9.56
			65-95	-16.94	13.49	-24.66	29.62
	D	PV	12-17	-0.26	0.56	0.17	0.50
			18-29	-0.20	0.69	0.02	0.58
			30-64	-0.13	0.47	-0.09	1.00
			65-95	-0.16	0.53	-0.49	2.51
		P	12-17	-0.87	7.06	2.33	9.31
			18-29	0.67	6.51	-1.22	5.25
			30-64	-1.57	7.47	-2.02	7.60
			65-95	-11.62	10.68	-13.63	18.00
Sagittal	ND	PV	12-17	1.10	16.15	3.90	18.25
			18-29	-3.72	8.82	-1.22	12.05
			30-64	-2.33	10.39	-2.80	22.95
			65-95	-10.27	20.83	-2.91	29.13
		P	12-17	1.10	16.15	3.90	18.25
			18-29	-3.72	8.82	-1.22	12.05
			30-64	-2.33	10.39	-2.80	22.95
			65-95	-10.27	20.83	-2.91	29.13
	D	PV	12-17	-0.57	1.44	0.30	0.80
			18-29	-0.22	0.60	-0.19	0.89
			30-64	0.01	0.85	0.25	0.84
			65-95	0.00	0.84	-0.31	1.76
		P	12-17	-4.46	29.14	-2.87	11.15
			18-29	-1.35	7.51	0.65	10.62
			30-64	-3.78	9.78	3.28	11.59
			65-95	-2.25	22.79	-5.94	16.73

Legend: ND – non-dominant (hand), D – dominant (hand), P – proprioceptive-only and PV-proprioceptive-visual; SC - sensory condition, MT – movement type.

In formal bias precision, which is related to proprioceptive condition and frontal movement to Emotivism in DP-TC test, we can observe higher emotional instability and variability in the eldest group (65-95) in both hands (Table 3). Women had higher error compared to men in the eldest group in frontal movement (with more positive bias: 37.54±29.21 mm vs. 22.91±25.65 mm) and transversal movement (with more negative bias for an average value: -24.66±29.62 mm); however, they showed less bias in an average group value in transversal movement compared to men, although they performed with greater variability (with more negative bias for a mean value: -2.91±29.13 mm vs. -10.27±20.83 mm).

Table 4. Descriptive statistics age * sex differences in speed (in msec)

			sex	Male		Female	
MT	**Hand**	**SC**	**age_group**	***M***	***SD***	***M***	***SD***
Frontal	ND	PV	12-17	7364	4454	7077	5202
			18-29	6629	3511	6410	3036
			30-64	5033	1220	5831	4165
			65-95	10776	6318	10975	4710
		P	12-17	5552	2585	4870	2731
			18-29	5803	3507	5555	1974
			30-64	4600	878	4529	2513
			65-95	7149	5129	8340	4237
	D	PV	12-17	7018	4121	7356	4118
			18-29	6582	3377	6427	3389
			30-64	5159	1185	4926	2782
			65-95	12854	7727	12168	6751
		P	12-17	5947	3688	5370	2639
			18-29	5731	3065	5378	2056
			30-64	4911	1136	3968	1916
			65-95	7976	5634	9062	5739
Transversal	ND	PV	12-17	7397	3842	8135	5214
			18-29	7150	3293	6645	2711
			30-64	5201	1140	5521	1644
			65-95	9293	4884	11410	5453
		P	12-17	5958	2715	7870	8419
			18-29	6543	3631	5480	2076
			30-64	4897	1047	4514	1274
			65-95	7869	3945	10423	8302

	D	PV	12-17	8884	4344	10515	5193
			18-29	8145	4037	10048	5606
			30-64	6131	1800	5610	1629
			65-95	14029	8933	13342	6882
		P	12-17	6198	3053	6441	3028
			18-29	6425	3683	6833	2936
			30-64	5098	1224	4147	945
			65-95	8970	4822	12848	7996
Sagittal	ND	PV	12-17	7906	5670	7820	4913
			18-29	7334	3564	6816	3139
			30-64	5489	1298	5527	2760
			65-95	10789	6080	11847	8233
		P	12-17	3829	10558	5517	2945
			18-29	6246	3081	5478	2074
			30-64	5065	1099	4366	1687
			65-95	7483	4350	9208	7126
	D	PV	12-17	8884	7255	8249	5119
			18-29	7518	3806	6811	3024
			30-64	5418	1037	5439	1960
			65-95	11329	6595	13922	10870
		P	12-17	5389	4205	6105	4057
			18-29	5862	4331	5449	1909
			30-64	5104	1003	4332	1170
			65-95	7467	3872	10305	7131

Legend: ND – non-dominant (hand), D – dominant (hand), P – proprioceptive-only and PV-proprioceptive-visual; SC - sensory condition, MT – movement type.

To simplify the output of the results of analysis, the models of precision (LL, D and F) and speed (T) depending on Age_group and Sex factors were described for three test conditions (MT – movement type – Frontal, Transversal and Sagittal; SC – sensory conditions – P – proprioceptive-only and PV – proprioceptive-visual, and Hand – ND – non-dominant and D - dominant). As per MANOVA with Bonferroni correction for precision and speed (detailed analysis is shown in Table 5), Age_group factor was significant for LL in all test conditions ($p<.001$), for Speed (T) in all except on sagittal movement ($p<.022$), ND hand and PV sensory condition; for D (directional) bias, it was significant only in transversal movement, D hand and P-test ($p<.001$) and in sagittal in PV-test (both hands) ($p<.033$), and for F (formal bias), Age_group was a significant factor in the frontal movement type (except on D hand and PV test) ($p<.001$) and in transversal movement in P-test (both hands) (p<.001). Sex was a significant factor only for precision, not for speed.

Table 5. Age group and sex effects on precision biases and speed

Test conditions			Model	Precision						Speed (T)	
			Factors of model	Line length (LL)		Directional bias (D)		Formal bias (F)			
MT	Hand	SC		*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Frontal	ND	P	Age_gr	11.48	<.001	2.34	.075	9.32	<.001	6.75	.000
		PV		20.19	<.001	0.21	.891	9.27	<.001	3.72	.013
	D	P		9.97	<.001	0.67	.571	14.23	<.001	11.80	.000
		PV		29.50	<.001	1.29	.278	2.28	.081	4.83	.003
Transversal	ND	P		35.02	<.001	1.59	.192	16.46	<.001	5.70	.001
		PV		139.55	<.001	1.51	.213	0.69	.560	3.31	.022
	D	P		56.25	<.001	7.89	<.001	14.18	<.001	6.96	.000
		PV		89.50	<.001	0.88	.451	0.54	.657	8.96	.000
Sagittal	ND	P		14.74	<.001	0.19	.904	1.83	.143	5.01	.003
		PV		18.08	<.001	4.75	.003	1.34	.263	1.98	.121
	D	P		9.62	<.001	0.36	.782	0.57	.637	5.56	.001
		PV		14.12	<.001	2.98	.033	0.69	.559	3.98	.010
Frontal	ND	P	Sex	6.24	.013	0.01	.929	0.09	.764	0.02	.895
		PV		5.80	.017	1.91	.169	6.50	.012	0.00	.947
	D	P		3.52	.062	1.77	.185	2.28	.133	0.04	.850
		PV		4.26	.040	3.51	.063	0.07	.786	0.06	.804
Transversal	ND	P		0.28	.599	5.53	.020	0.16	.685	0.63	.429
		PV		15.68	<.001	0.47	.494	2.24	.137	0.58	.449
	D	P		0.41	.521	0.08	.771	0.03	.852	0.27	.603
		PV		15.80	<.001	0.38	.538	0.36	.550	1.02	.314
Sagittal	ND	P		2.10	.149	0.20	.657	1.30	.256	0.01	.909
		PV		0.61	.437	2.15	.144	0.04	.842	0.14	.709
	D	P		2.01	.158	0.68	.412	0.40	.530	0.06	.806
		PV		0.19	.665	2.98	.086	1.32	.252	0.41	.525
Frontal	ND	P	Age_gr * Sex	2.43	.067	2.53	.059	0.56	.643	0.06	.982
		PV		2.73	.045	0.55	.652	0.14	.934	0.41	.747
	D	P		1.15	.328	0.65	.583	2.16	.094	0.06	.979
		PV		5.35	.001	0.24	.870	2.64	.051	0.33	.805
Transversal	ND	P		2.13	.098	2.60	.053	2.49	.062	0.60	.615
		PV		5.98	.001	0.72	.542	1.96	.122	1.10	.352
	D	P		1.15	.331	2.56	.056	0.68	.564	0.45	.719
		PV		8.75	<.001	0.38	.768	0.95	.419	1.39	.248
Sagittal	ND	P		0.91	.438	0.49	.686	0.30	.822	0.13	.941
		PV		1.01	0.389	0.13	.943	1.38	.251	0.39	.762
	D	P		1.19	0.317	1.36	.258	0.54	.659	0.47	.706
		PV		0.13	0.942	0.78	.506	1.90	.131	0.85	.470

Legend: ND – non-dominant (hand), D – dominant (hand), P – proprioceptive-only and PV- proprioceptive-visual; SC - sensory condition, MT – movement type. Size effects: η^2_p: Age group factor – Wilks L =.729, Sex – Wilks L=.450, Age group*Sex – Wilks L=.415.

R^2_{adj} values are shown in Table 6 for the model:

fine motor behaviour in various test conditions = age + sex + sex*age,

from which it is seen that the highest fit (as per percentage of explicable variance) belongs to LL bias, especially in transversal movement type.

Table 6. R^2_{adj} values for the model of factors of study: sex and age (represented under different test conditions)

			R^2_{adj} (model: age + sex + age*sex)			
			Observable variables for precision and speed			
	Hand	**SC**	**LL**	**D**	**F**	**T**
Frontal	**ND**	**P**	.154	.051	.120	.096
		PV	.282	-.018	.104	.043
	D	**P**	.122	.006	.234	.186
		PV	.387	-.004	.047	.069
Transversal	**ND**	**P**	.388	.040	.209	.095
		PV	.767	-.001	.019	.056
	D	**P**	.500	.128	.175	.128
		PV	.688	-.017	-.011	.189
Sagittal	**ND**	**P**	.174	-.024	.001	.066
		PV	.217	.143	-.006	.017
	D	**P**	.118	-.003	-.018	.087
		PV	.158	.111	.021	.072

Legend: SC – sensory condition: P – proprioceptive-only; PV – proprioceptive-visual; ND – non-dominant and D – dominant hand correspondently; LL – line length, D – directional (bias), F – formal (bias) and T – time (speed).

Post-hoc analysis of MANOVA for age factor revealed that the age-group of 65-95 years performed with a statistically significant level ($p \leq .016$) compared to the other age groups for all test conditions in line length (LL) and some test conditions with variables D, F and T (Table 7 and Table 8).

Table 7. MANOVA analysis with Bonferroni correction for precision in size (LL) and velocity (T) in four age subgroups

					Precision (LL, mm)		Velocity (T, msec)	
MT	Hand	SC	(I) group	(J) group	Mean dif. (I-J)	p	Mean dif. (I-J)	p
Frontal	ND	P	12 - 17	18 - 29	-1.39	1.000	701	1.000
				30 - 64	-1.10	1.000	1789	1.000
				65 - 95	-16.97*	<.001	-3655*	.009
			18 - 29	12 - 17	1.39	1.000	-701	1.000
				30 - 64	0.29	1.000	1088	1.000
				65 - 95	-15.58*	<.001	-4356*	.001
			30 - 64	12 - 17	1.10	1.000	-1789	1.000
				18 - 29	-0.29	1.000	-1088	1.000
				65 - 95	-15.88*	<.001	-5444*	.004
			65 - 95	12 - 17	16.97*	<.001	3655*	.009
				18 - 29	15.58*	<.001	4356*	.001
				30 - 64	15.88*	<.001	5444*	.004
		PV	12 - 17	18 - 29	1.52	.126	-467	1.000
				30 - 64	1.23	.353	647	1.000
				65 - 95	6.66*	<.001	-2534*	.026
			18 - 29	12 - 17	-1.52	.126	467	1.000
				30 - 64	-0.29	1.000	1114	1.000
				65 - 95	5.14*	<.001	-2066	.089
			30 - 64	12 - 17	-1.23	.353	-647	1.000
				18 - 29	0.29	1.000	-1114	1.000
				65 - 95	5.43*	<.001	-3180	.057
			65 - 95	12 - 17	-6.66*	<.001	2533*	.026
				18 - 29	-5.14*	<.001	2066	.089
				30 - 64	-5.43*	<.001	3180	.057
	D	P	12 - 17	18 - 29	0.37	1.000	682	1.000
				30 - 64	-0.46	1.000	2144	1.000
				65 - 95	-15.05*	<.001	-5325*	<.001
			18 - 29	12 - 17	-0.37	1.000	-682	1.000
				30 - 64	-0.83	1.000	1462	1.000
				65 - 95	-15.42*	<.001	-6007*	<.001
			30 - 64	12 - 17	0.46	1.000	-2144	1.000
				18 - 29	0.83	1.000	-1462	1.000
				65 - 95	-14.59*	<.001	-7469*	<.001
			65 - 95	12 - 17	15.05*	<.001	5325*	<.001
				18 - 29	15.42*	<.001	6007*	<.001
				30 - 64	14.59*	<.001	7469*	<.001
		PV	12 - 17	18 - 29	1.53*	.036	103	1.000
				30 - 64	0.56	1.000	1219	1.000

				65 - 95	6.70*	<.001	-2860*	.022
			18 - 29	12 - 17	-1.53*	.036	-103	1.000
				30 - 64	-0.97	.266	1115	1.000
				65 - 95	5.17*	<.001	-2964*	.010
			30 - 64	12 - 17	-0.56	1.000	-1219	1.000
				18 - 29	0.97	.266	-1115	1.000
				65 - 95	6.14*	<.001	-4079*	.017
			65 - 95	12 - 17	-6.70*	<.001	2860*	.022
				18 - 29	-5.17*	<.001	2964*	.010
				30 - 64	-6.14*	<.001	4079*	.017
Transversal	ND	P	12 - 17	18 - 29	20.66*	<.001	868	1.000
				30 - 64	14.90*	.007	2405	.480
				65 - 95	-35.30*	<.001	-2585	.079
			18 - 29	12 - 17	-20.66*	<.001	-868	1.000
				30 - 64	-5.76	.880	1537	1.000
				65 - 95	-55.96*	<.001	-3454*	.004
			30 - 64	12 - 17	-14.90*	.007	-2405	.480
				18 - 29	5.76	.880	-1537	1.000
				65 - 95	-50.20*	<.001	-4991*	.004
			65 - 95	12 - 17	35.30*	<.001	2585	.079
				18 - 29	55.96*	<.001	3454*	.004
				30 - 64	50.20*	<.001	4991*	.004
		PV	12 - 17	18 - 29	22.31*	<.001	903	1.000
				30 - 64	17.35*	<.001	2209	1.000
				65 - 95	3.91*	.016	-2232	.409
			18 - 29	12 - 17	-22.31*	<.001	-903	1.000
				30 - 64	-4.96*	<.001	1306	1.000
				65 - 95	-18.40*	<.001	-3135*	.048
			30 - 64	12 - 17	-17.35*	<.001	-2209	1.000
				18 - 29	4.96*	<.001	-1306	1.000
				65 - 95	-13.44*	<.001	-4441	.056
			65 - 95	12 - 17	-3.91*	.016	2232	.409
				18 - 29	18.40*	<.001	3135*	.048
				30 - 64	13.44*	<.001	4441	.056
	D	P	12 - 17	18 - 29	19.84*	<.001	603	1.000
				30 - 64	15.50*	<.001	3829	.217
				65 - 95	5.92*	<.001	-3986*	.025
			18 - 29	12 - 17	-19.84*	<.001	-603	1.000
				30 - 64	-4.33*	<.001	3226	.421
				65 - 95	-13.92*	<.001	-4589*	.004
			30 - 64	12 - 17	-15.50*	<.001	-3829	.217
				18 - 29	4.33*	<.001	-3226	.421
				65 - 95	-9.59*	<.001	-7815*	<.001
			65 - 95	12 - 17	-5.92*	<.001	3986*	.025
				18 - 29	13.92*	<.001	4589*	.004

				30 - 64	9.59*	<.001	7815*	<.001
		PV	12 - 17	18 - 29	19.84*	<.001	-310	1.000
				30 - 64	15.50*	<.001	1697	1.000
				65 - 95	5.92*	<.001	-4589*	<.001
			18 - 29	12 - 17	-19.84*	<.001	310	1.000
				30 - 64	-4.33*	<.001	2007	.928
				65 - 95	-13.92*	<.001	-4280*	<.001
			30 - 64	12 - 17	-15.50*	<.001	-1697	1.000
				18 - 29	4.33*	<.001	-2007	.928
				65 - 95	-9.59*	<.001	-6287*	<.001
			65 - 95	12 - 17	-5.92*	<.001	4589*	<.001
				18 - 29	13.92*	<.001	4280*	<.001
				30 - 64	9.59*	<.001	6287*	<.001
Sagittal	ND	P	12 - 17	18 - 29	0.63	1.000	788	1.000
				30 - 64	-1.80	1.000	2355	1.000
				65 - 95	-15.53*	<.001	-3455	.059
			18 - 29	12 - 17	-0.63	1.000	-788	1.000
				30 - 64	-2.44	1.000	1567	1.000
				65 - 95	-16.16*	<.001	-4243*	.006
			30 - 64	12 - 17	1.80	1.000	-2355	1.000
				18 - 29	2.44	1.000	-1567	1.000
				65 - 95	-13.72*	<.001	-5810*	.011
			65 - 95	12 - 17	15.53*	<.001	3455	.059
				18 - 29	16.16*	<.001	4243*	.006
				30 - 64	13.72*	<.001	5810*	.011
		PV	12 - 17	18 - 29	1.35	.363	-1189	1.000
				30 - 64	2.19*	.013	-42	1.000
				65 - 95	6.57*	<.001	-3672	.134
			18 - 29	12 - 17	-1.35	.363	1189	1.000
				30 - 64	0.84	1.000	1147	1.000
				65 - 95	5.23*	<.001	-2484	.632
			30 - 64	12 - 17	-2.19*	.013	42	1.000
				18 - 29	-0.84	1.000	-1147	1.000
				65 - 95	4.39*	<.001	-3630	.607
			65 - 95	12 - 17	-6.57*	<.001	3672	.134
				18 - 29	-5.23*	<.001	2484	.632
				30 - 64	-4.39*	<.001	3630	.607
	D	P	12 - 17	18 - 29	0.67	1.000	1402	1.000
				30 - 64	-1.76	1.000	3138	.817
				65 - 95	-16.35*	<.001	-4059	.067
			18 - 29	12 - 17	-0.67	1.000	-1402	1.000
				30 - 64	-2.44	1.000	1736	1.000
				65 - 95	-17.03*	<.001	-5461*	.003
			30 - 64	12 - 17	1.76	1.000	-3138	.817
				18 - 29	2.44	1.000	-1736	1.000

		65 - 95	-14.59*	<.001	-7197*	.008
	65 - 95	**12 - 17**	16.35*	<.001	4059	.067
		18 - 29	17.03*	<.001	5461*	.003
		30 - 64	14.59*	<.001	7197*	.008
PV	**12 - 17**	**18 - 29**	0.51	1.000	92	1.000
		30 - 64	1.42	.305	1029	1.000
		65 - 95	5.56*	<.001	-3139*	.039
	18 - 29	**12 - 17**	-0.51	1.000	-92	1.000
		30 - 64	0.92	.904	938	1.000
		65 - 95	5.05*	<.001	-3231*	.021
	30 - 64	**12 - 17**	-1.42	.305	-1029	1.000
		18 - 29	-0.92	.904	-938	1.000
		65 - 95	4.13*	<.001	-4168	.054
	65 - 95	**12 - 17**	-5.56*	<.001	3139*	.039
		18 - 29	-5.05*	<.001	3231*	.021
		30 - 64	-4.13*	<.001	4168	.054

Legend: * *p*<.05. ND –non-dominant hand, D – dominant hand, P - proprioceptive-only, PV – proprioceptive-visual, MT – movement type, SC – sensory condition.

Table 8. MANOVA analysis with Bonferroni correction for precision in spatial deviations (D and F) in four age subgroups

					Precision			
					Directional bias (mm)		Formal bias (mm)	
MT	**Hand**	**SC**	**(I) group**	**(J) group**	**Mean dif. (I-J)**	***p***	**Mean dif. (I-J)**	***p***
Frontal	**ND**	**P**	**12 - 17**	**18 - 29**	-2.45	1.000	2.97	1.000
				30 - 64	-7.30	.195	-0.98	1.000
				65 - 95	-7.43	.216	-14.53*	<.001
			18 - 29	**12 - 17**	2.45	1.000	-2.97	1.000
				30 - 64	-4.84	.800	-3.96	1.000
				65 - 95	-4.98	.835	-17.50*	<.001
			30 - 64	**12 - 17**	7.30	.195	0.98	1.000
				18 - 29	4.84	.800	3.96	1.000
				65 - 95	-0.13	1.000	-13.55*	.002
			65 - 95	**12 - 17**	7.43	.216	14.53*	<.001
				18 - 29	4.98	.835	17.50*	<.001
				30 - 64	0.13	1.000	13.55*	.002
		PV	**12 - 17**	**18 - 29**	0.04	1.000	-0.01	1.000
				30 - 64	-0.20	1.000	0.00	1.000
				65 - 95	0.30	1.000	-1.31*	<.001
			18 - 29	**12 - 17**	-0.04	1.000	0.01	1.000
				30 - 64	-0.25	1.000	0.02	1.000
				65 - 95	0.26	1.000	-1.29*	<.001
			30 - 64	**12 - 17**	0.20	1.000	0.00	1.000

				18 - 29	0.25	1.000	-0.02	1.000
				65 - 95	0.51	1.000	-1.31*	<.001
			65 - 95	12 - 17	-0.30	1.000	1.31*	<.001
				18 - 29	-0.26	1.000	1.29*	<.001
				30 - 64	-0.51	1.000	1.311*	<.001
	D	P	12 - 17	18 - 29	-2.54	1.000	5.53	.449
				30 - 64	-5.32	.953	6.52	.355
				65 - 95	-2.81	1.000	-14.60*	<.001
			18 - 29	12 - 17	2.54	1.000	-5.53	.449
				30 - 64	-2.79	1.000	0.99	1.000
				65 - 95	-0.28	1.000	-20.13*	<.001
			30 - 64	12 - 17	5.32	.953	-6.52	.355
				18 - 29	2.79	1.000	-0.99	1.000
				65 - 95	2.51	1.000	-21.12*	<.001
			65 - 95	12 - 17	2.81	1.000	14.60*	<.001
				18 - 29	0.28	1.000	20.13*	<.001
				30 - 64	-2.51	1.000	21.12*	<.001
		PV	12-17	18 - 29	-0.16	1.000	-0.34	.626
				30 - 64	-0.34	1.000	-0.54	.140
				65 - 95	0.44	1.000	-0.52	.206
			18 - 29	12 - 17	0.16	1.000	0.34	.626
				30 - 64	-0.18	1.000	-0.19	1.000
				65 - 95	0.61	.693	-0.18	1.000
			30 - 64	12 - 17	0.34	1.000	0.54	.140
				18 - 29	0.18	1.000	0.19	1.000
				65 - 95	0.78	.384	0.02	1.000
			65 - 95	12 - 17	-0.44	1.000	0.52	.206
				18 - 29	-0.61	.693	0.18	1.000
				30 - 64	-0.78	.384	-0.02	1.000
Transversal	ND	P	12 - 17	18 - 29	8.37	.446	1.40	1.000
				30 - 64	6.81	1.000	3.64	1.000
				65 - 95	10.55	.312	21.36*	<.001
			18 - 29	12 - 17	-8.37	.446	-1.40	1.000
				30 - 64	-1.57	1.000	2.23	1.000
				65 - 95	2.17	1.000	19.96*	<.001
			30 - 64	12-17	-6.81	1.000	-3.64	1.000
				18 - 29	1.57	1.000	-2.23	1.000
				65 - 95	3.74	1.000	17.72*	<.001
			65 - 95	12 - 17	-10.55	.312	-21.36*	<.001
				18 - 29	-2.17	1.000	-19.96*	<.001
				30 - 64	-3.74	1.000	-17.72*	<.001
		PV	12 - 17	18 - 29	0.14	1.000	0.03	1.000
				30 - 64	0.02	1.000	0.08	1.000
				65 - 95	1.26	.370	0.33	1.000
			18 - 29	12 - 17	-0.14	1.000	-0.03	1.000
				30 - 64	-0.13	1.000	0.04	1.000
				65 - 95	1.12	.492	0.30	1.000
			30 - 64	12 - 17	-0.02	1.000	-0.08	1.000
				18 - 29	0.13	1.000	-0.04	1.000
				65 - 95	1.24	.462	0.26	1.000
			65 - 95	12 - 17	-1.26	.370	-0.33	1.000
				18 - 29	-1.12	.492	-0.30	1.000

				30 - 64	-1.24	.462	-0.26	1.000
	D	P	**12 - 17**	**18 - 29**	-2.87	1.000	1.01	1.000
				30 - 64	-3.04	1.000	2.52	1.000
				65 - 95	15.21*	.003	13.36*	<.001
			18 - 29	**12 - 17**	2.87	1.000	-1.01	1.000
				30 - 64	-0.17	1.000	1.52	1.000
				65 - 95	18.08*	<.001	12.35*	<.001
			30 - 64	**12 - 17**	3.04	1.000	-2.52	1.000
				18 - 29	0.17	1.000	-1.52	1.000
				65 - 95	18.25*	<.001	10.83*	<.001
			65 - 95	**12 - 17**	-15.21*	.003	-13.36*	<.001
				18 - 29	-18.08*	<.001	-12.35*	<.001
				30 - 64	-18.25*	<.001	-10.83*	<.001
		PV	**12 - 17**	**18 - 29**	0.10	1.000	0.04	1.000
				30 - 64	-0.24	1.000	0.06	1.000
				65 - 95	-1.43	1.000	0.28	1.000
			18 - 29	**12 - 17**	-0.10	1.000	-0.04	1.000
				30 - 64	-0.34	1.000	0.02	1.000
				65 - 95	-1.53	.762	0.23	1.000
			30 - 64	**12 - 17**	0.24	1.000	-0.06	1.000
				18 - 29	0.34	1.000	-0.02	1.000
				65 - 95	-1.19	1.000	0.21	1.000
			65 - 95	**12 - 17**	1.43	1.000	-0.28	1.000
				18 - 29	1.53	.762	-0.23	1.000
				30 - 64	1.19	1.000	-0.21	1.000
Sagittal	ND	P	**12 - 17**	**18 - 29**	-1.96	1.000	4.97	.886
				30 - 64	-0.04	1.000	5.06	1.000
				65 - 95	-1.22	1.000	9.09	.135
			18 - 29	**12 - 17**	1.96	1.000	-4.97	.886
				30 - 64	1.92	1.000	0.10	1.000
				65 - 95	0.74	1.000	4.12	1.000
			30 - 64	**12 - 17**	0.04	1.000	-5.06	1.000
				18 - 29	-1.92	1.000	-0.10	1.000
				65 - 95	-1.18	1.000	4.03	1.000
			65 - 95	**12 - 17**	1.22	1.000	-9.09	.135
				18 - 29	-0.74	1.000	-4.12	1.000
				30 - 64	1.18	1.000	-4.03	1.000
		PV	**12 - 17**	**18 - 29**	-0.30	1.000	0.24	1.000
				30 - 64	-1.75*	.005	0.59	.348
				65 - 95	-0.05	1.000	0.42	1.000
			18 - 29	**12 - 17**	0.30	1.000	-0.24	1.000
				30 - 64	-1.44*	.022	0.35	1.000
				65 - 95	0.25	1.000	0.18	1.000
			30 - 64	**12 - 17**	1.75*	.005	-0.59	.348
				18 - 29	1.44*	.022	-0.35	1.000
				65 - 95	1.70*	.017	-0.17	1.000
			65 - 95	**12 - 17**	0.05	1.000	-0.42	1.000
				18 - 29	-0.25	1.000	-0.18	1.000
				30 - 64	-1.70*	.017	0.17	1.000
	D	P	**12 - 17**	**18 - 29**	1.43	1.000	-3.31	1.000
				30 - 64	3.74	1.000	-3.41	1.000
				65 - 95	2.79	1.000	0.43	1.000
			18 - 29	**12 - 17**	-1.43	1.000	3.31	1.000

		30 - 64	2.31	1.000	-0.10	1.000
		65 - 95	1.36	1.000	3.74	1.000
	30 - 64	**12 - 17**	-3.74	1.000	3.41	1.000
		18 - 29	-2.31	1.000	0.10	1.000
		65 - 95	-0.96	1.000	3.84	1.000
	65 - 95	**12 - 17**	-2.79	1.000	-0.43	1.000
		18 - 29	-1.36	1.000	-3.74	1.000
		30 - 64	0.96	1.000	-3.84	1.000
PV	**12 - 17**	**18 - 29**	0.03	1.000	0.07	1.000
		30 - 64	-0.61	1.000	-0.26	1.000
		65 - 95	1.04	.322	0.02	1.000
	18 - 29	**12 - 17**	-0.03	1.000	-0.07	1.000
		30 - 64	-0.64	1.000	-0.33	1.000
		65 - 95	1.01	.296	-0.05	1.000
	30 - 64	**12 - 17**	0.61	1.000	0.26	1.000
		18 - 29	0.64	1.000	0.33	1.000
		65 - 95	1.65*	.021	0.28	1.000
	65 - 95	**12 - 17**	-1.04	.322	-0.02	1.000
		18 - 29	-1.01	.296	0.05	1.000
		30 - 64	-1.65*	.021	-0.28	1.000

Legend: * *p*<.05. ND –non-dominant hand, D – dominant hand, P - proprioceptive-only, PV – proprioceptive-visual, MT – movement type, SC – sensory condition.

4.2.2. Quadratic regression analysis by age

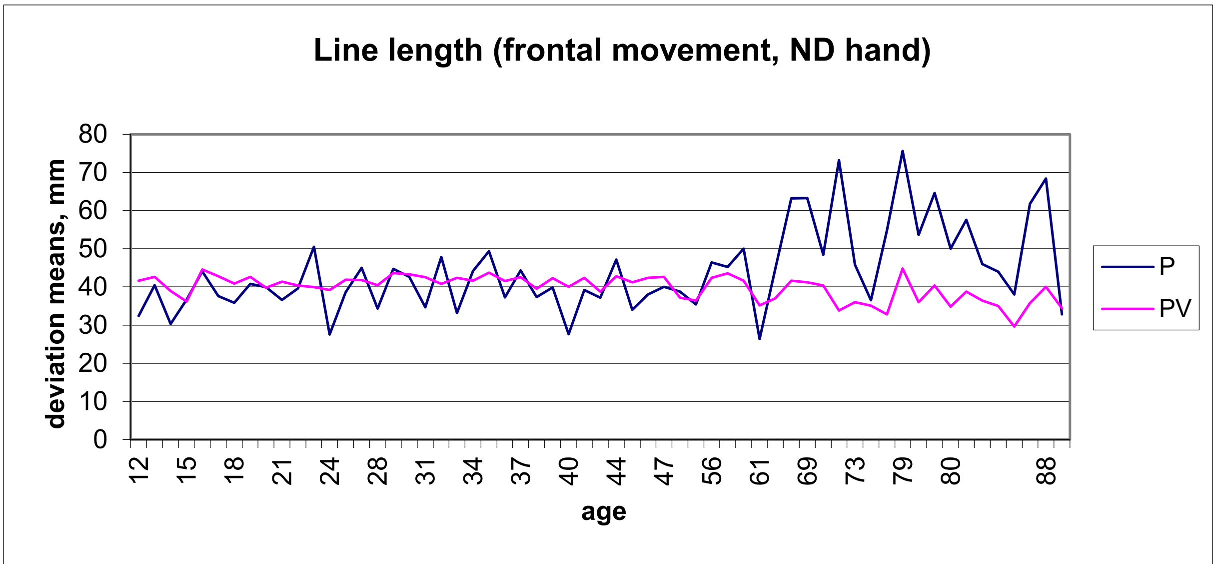
Since some studies presented in the biographical prior review showed a more complex relationship depending on age for both brain maturation and motor precision, here I would like to check the quadratic relationship model for all data of factor age (without splitting on groups where, on each level, this interdependence was more lineal). For this reason, the model to test for age factor for the whole data, ranged from 12 to 95 years old) was the following:

Precision (LL, D and F/ test conditions – MT, SC and Hand)
Speed (T/ test conditions – MT, SC and Hand)

$$\text{Age}^2 + \text{Age} + C$$

The gross trend in age-dependent differences can be observed in descriptive statistical data that reflect average values in precision (Tables 1-3) and speed (Table 4) for both sexes in four age subgroups: 1) 12-17 years old (N=41); 2) 18-29 years old (N=63); 3) 30-64 years old

(N=67), and 4) 65-95 years old (N=25). The original data, obtained from the test, for both precision and velocity, were performed for curvilinear estimation (quadratic) to age age-dependent differences. The quadratic approximation is more 'logical' for the gross estimation, since it reflects the fact that in both the early and late stages of life fine motor behaviour is less precise. The precision of fine motor performance was worse at the initial measurement point (age 12), after which it improved with age until reaching its optimum point (i.e. where the movement was made with the highest precision). Afterwards, approximately at age of 50-60, it started to decline again as is seen from mean values of LL[2] at different ages (Fig. 4.1, 4.2 and 4.3).



[2] This variable was of best fit for a quadratic polynomial regression analysis under all test conditions compared to other variables (will be described in detail below).

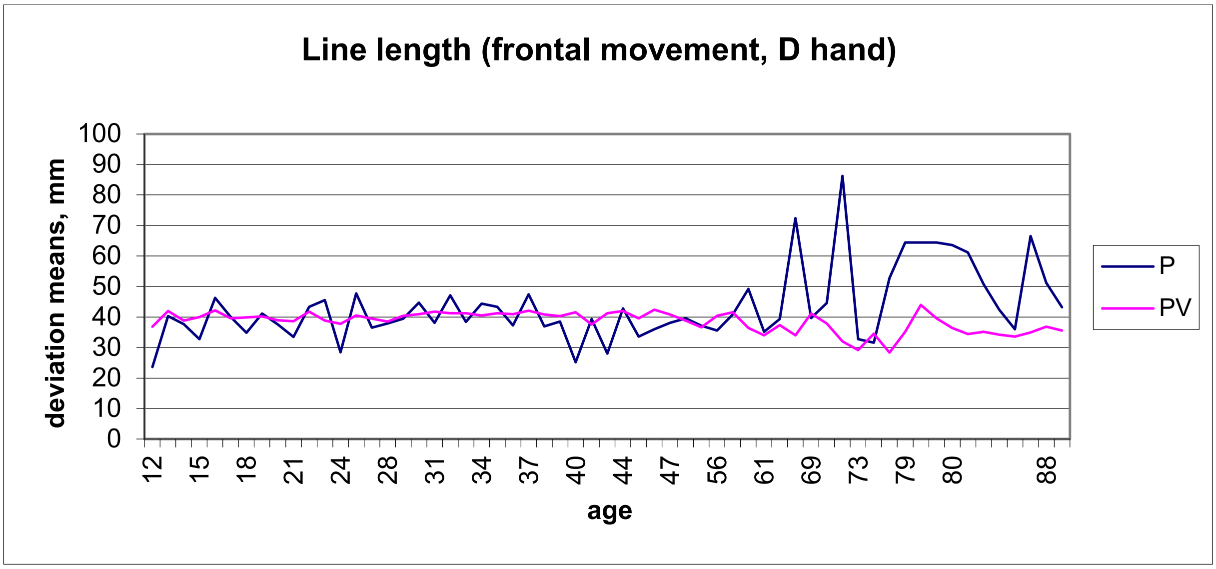
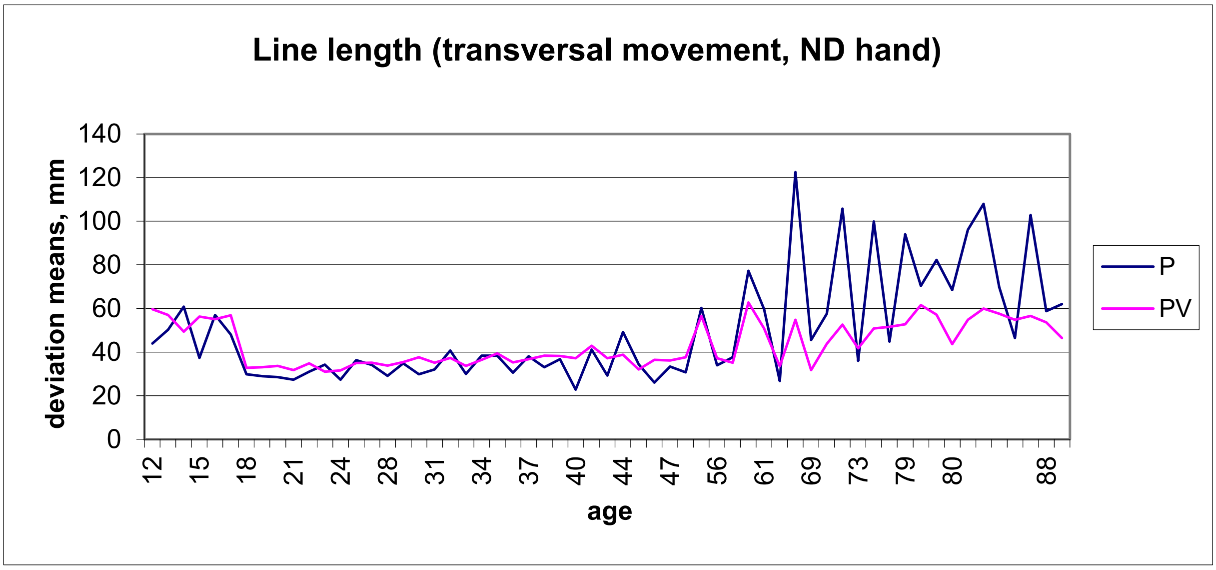


Figure 4.1. LL means (Y-axis, mm) plotted against age (X-axis, years) for frontal movements: non-dominant hand (above) and dominant hand (below) under the P (dark line) and PV (light line) test conditions.



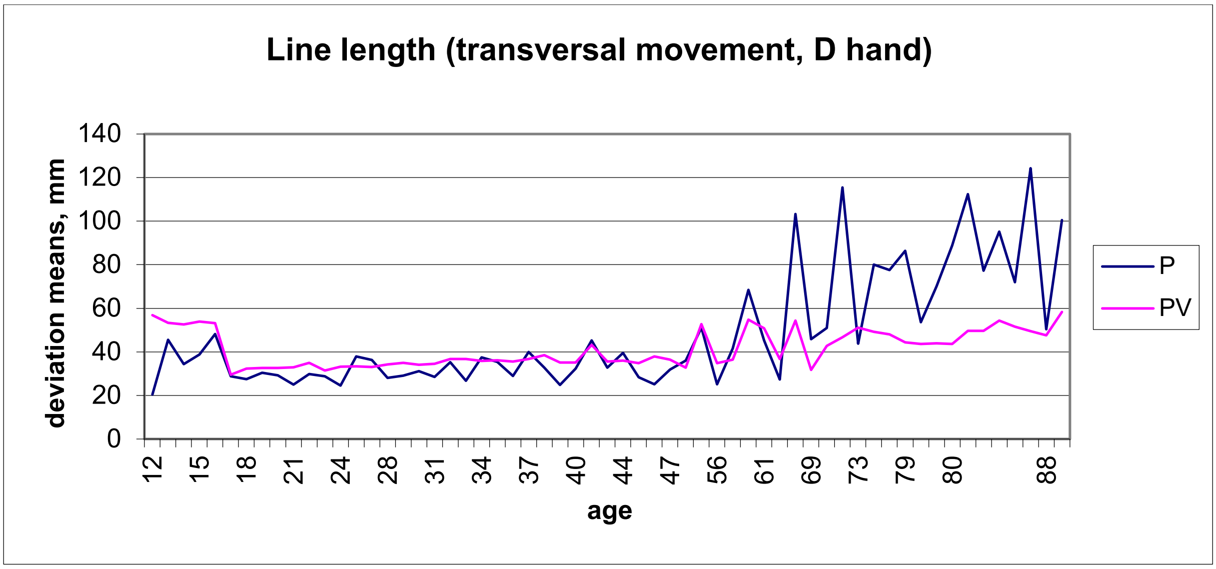
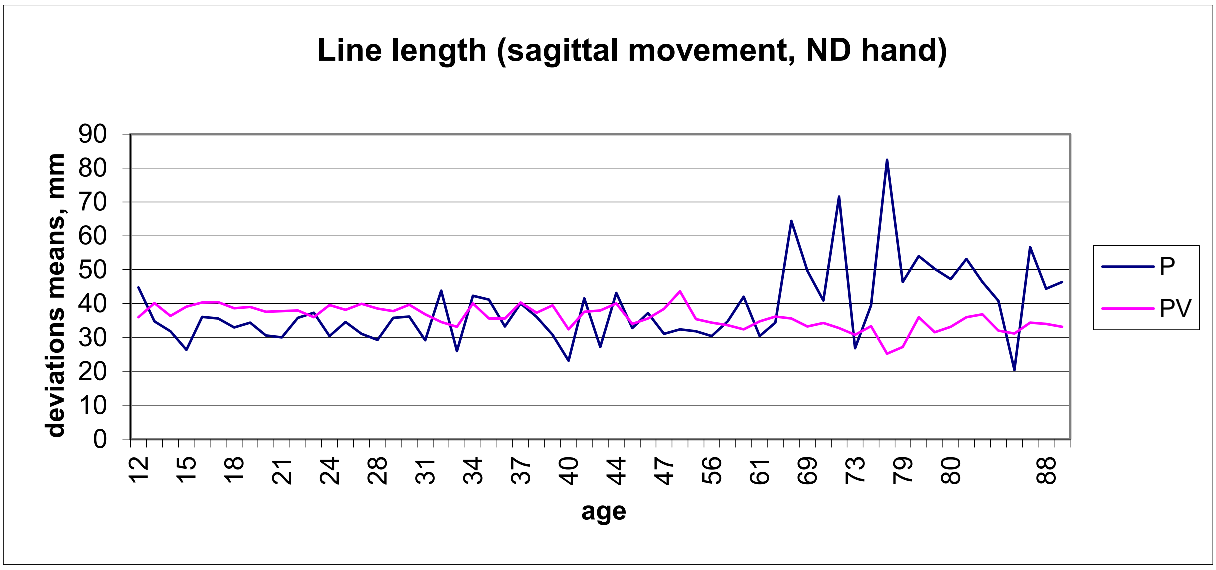


Figure 4.2. LL means (Y-axis, mm) plotted against age (X-axis, years) for transversal movements: non-dominant hand (above) and dominant hand (below) under the P (dark line) and PV (light line) test conditions.



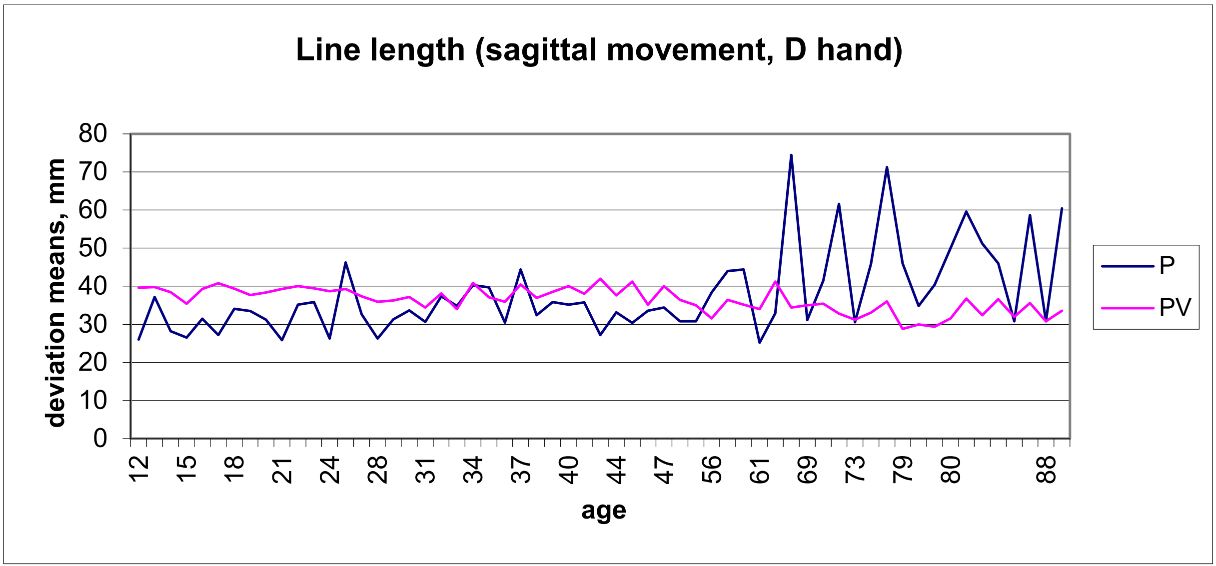


Figure 4.3. LL means (Y-axis, mm) plotted against age (X-axis, years) for sagittal movements: non-dominant hand (above) and dominant hand (below) under the P (dark line) and PV (light line) test conditions.

In general, sensoriomotor development across life span shows a complex behaviour that is similar to a polynomial dependence on age, with its corresponding cycles and peaks. Although there is considerable variation on the individual level, it is nonetheless possible to identify common population trends (means). Figures 4.1, 4.2 and 4.3 represent in graphical form an analysis of the variation in means for size (LL) for the P and PV conditions in relation to the subjects' age. It can be seen that the P and PV feedback functions are well-matched after 20 years of age, and begin to diverge more clearly after 48-50 years. Moreover, the P condition shows greater imprecision in fine motor performance after 48-50 years, which could also contribute to a greater change in the overall performance under the PV test condition (the amplitude of PV plots was also higher after this age, as can be seen in Figure 4.2 for transverse movements). If we drew an adjusted smoothing line through the data we would see that imprecision in transverse movements tends to increase with age. As regards frontal movements, their means are generally more varied (sharper behaviour with many peaks); especially under the P test condition in comparison with the results for transverse performance. However, after the age of approximately 50 years, the plot shows a similar trend towards greater imprecision. In sagittal movement type, the mean values for P and PV conditions appear to be more separated, in P LL tending to be less in size before approximate 60 years, after which, the opposite situation was observed (Figure 4.3).

The inflection points (minimum and maximum) of parabolas correspond to the values for greatest precision and best performance speed. Therefore, those inflection points, assessed for an average population mean for the given sample (196 subjects), provide an estimate of the point on the x-axis (age) that reflects the best fine motor performance. The graphical analysis shows that this point corresponds to the period of maturity (30 – 60 years), after which an individual's performance begins to decline due to natural aging.

These inflection points were calculated by equating to zero the first derivatives of the functions found for each observable variable by quadratic regression (*):

$f(age) = a*age^2 + b*age + C$

$f'(age) = 2a*age + b = 0 \rightarrow age = -b/2a$ (*).

4.2.2.1. Regressions for precision

1) LL – line length size, mm

This revealed that for transverse movements the critical age point for the proprioceptive function (P condition) was (for ND/D hands respectively) 35/31, while that for the visuo-proprioceptive function (PV condition) was 45/48. As regards frontal movements, the regressions showed a poorer fit, although the results were almost the same for all observable variables: critical ages of 26 for the right hand under the PV condition, and critical age of 22 and 23 for the other three variables. In sagittal movement, in PV condition slopes were close to zero and the only significant inflection point was found for ND hand and P-test, as 10 years (Table 9).

Quadratic equations related to changes in fine motor precision for subjects of different ages (12 to 95 years) were derived for both test conditions (P and PV), for both hands (non-dominant and dominant) and for frontal, transverse and sagittal movements separately. The best regressions, together with the highest R/R^2adj values (see Table 9), were obtained for transverse movements, which therefore provide a better prediction of the inflection age points. However, each movement type could reflect various developmental stages and give different information.

Table 9. Quadratic regression analysis for LL

MT	Hand	SC	R^2_{adj}	ANOVA, F	B (age^2)	B (age)	Inflection points (age)
Frontal	ND	P	.11	12.85***	0.004	0.179	22.4 (*p*=.059)
		PV	.14	17.30***	-0.002	0.087	21.8*
	D	P	.10	12.12***	0.005	-0.229	22.9*
		PV	.30	42.29***	-0.001	0.052	26**
Transversal	ND	P	.34	51.07***	0.023	-1.587	34.5***
		PV	.34	50.14***	0.013	-1.158	44.5***
	D	P	.48	92.25***	0.022	-1.36	30.9***
		PV	.24	31.20***	0.010	-0.947	47.4***
Sagittal	ND	P	.15	17.80***	0.003	-0.061	10.2***
		PV	.22	28.15***	≈0		N/A
	D	P	.11	12.93***	0.004	-0.151	18.9 (*p*=.08)
		PV	.17	20.80***	≈0		N/A

Legend: ND – non-dominant (hand), D – dominant (hand), P – proprioceptive-only and PV-proprioceptive-visual; SC - sensory condition, MT – movement type.
Level of significance: * $p<.05$, ** $p<.01$, *** $p<.001$.

2) D – directional bias, mm

In directional bias the quadratic function confirmed itself as a significant model in P-test in frontal (ND hand), transversal movements (both hands, ND only in men) and sagittal (D hand). In PV-test, this model was significant only in sagittal movement (both hands). The corresponding inflection points for directional bias were in P-test: 64 years, 32 and 39 years in transversal and 49 in sagittal; in PV-test, 47 and 61 years (Table 10).

Table 10. Quadratic regression analysis for D (directional) bias

MT	Hand	SC	R^2_{adj}	ANOVA, F	B (age^2)	B (age)	Inflection points (age)	
Frontal	ND	P	.04	4.74**	-0.004	0.512	64*	
		PV	.01	0.01			N/A	
	D	P	.01	2.18			(54.6)	
		PV	-.00	0.06	-0.004	0.437	N/A	
Transversal	ND	P	-0.01	3.09*	≈0		N/A	(male: 32.3*, female: N/A)
		PV	0.01	1.68			N/A	
	D	P	.10	12.29***	-0.009	0.700	38.9***	
		PV	0.02	1.12			N/A	
Sagittal	ND	P	-0.01	0.03			N/A	
		PV	0.15	17.52***	-0.002	0.186	46.5***	
	D	P	0.01	2.17	-0.005	0.485	48.5*	
		PV	0.09	10.22***	-0.001	0.121	60.5***	

Legend: ND – non-dominant (hand), D – dominant (hand), P – proprioceptive-only and PV-proprioceptive-visual; SC - sensory condition, MT – movement type.
Level of significance: * $p<.05$, ** $p<.01$, *** $p<.001$.

3) F – formal bias, mm

For formal bias type, no one significant model for quadratic polynomial was found in sagittal movement type. In other movement types, the significant models were confirmed by regression analysis for P-test only: 32 and 38 years for ND/D hands in frontal movement and 25 years for ND hand in transversal movement.

Table 11. Quadratic regression analysis for F (formal) bias

MT	Hand	SC	R^2_{adj}	ANOVA, F	B (age^2)	B (age)	Inflection points (age)
Frontal	ND	P	0.18	22.15***	0.008	-0.517	32.3***
		PV	0.07	8.50***	≈0		N/A (male/female: N/A)
	D	P	0.24	31.88	0.014	1.058	37.8***
		PV	0.02	3.09*	≈0		N/A
Transversal	ND	P	0.20	25.02***	-0.006	0.295	24.6**
		PV	0.01	2.00			N/A
	D	P	0.16	19.02***	-0.002	0.034	8.5 (*p*=.113)
		PV	0.00	1.12			N/A
Sagittal	ND	P	-0.01	0.03			N/A
		PV	-0.00	0.18			N/A
	D	P	-0.01	0.41			N/A
		PV	0.00	1.27			N/A

Legend: ND – non-dominant (hand), D – dominant (hand), P – proprioceptive-only and PV-proprioceptive-visual; SC - sensory condition, MT – movement type.
Level of significance: * $p<.05$, ** $p<.01$, *** $p<.001$.

4.2.2.2. Regressions for speed

As far as a quadratic regression analysis for speed performance is concerned, the quadratic model was significant in all movement * test condition types, except on ND hand, P-test in sagittal movement (Table 12). The inflection points (statistically significant ones) were quite homogeneous for all test conditions (movement types, sensory conditions and hands), indicating ages ranging from 33 to 40 years old (Table 12).

Table 12. Quadratic regression analysis for speed (T)

MT	Hand	SC	R^2_{adj}	ANOVA, F	B (age^2)	B (age)	Inflection points (age)
Frontal	ND	P	0.07	6.30**	1.275	-88.16	34.6 (*p*=.10)
		PV	0.14	11.61***	2.598	-193.199	37.2**
	D	P	0.10	8.76***	2.054	-156.612	38.1*
		PV	0.22	20.02***	3.497	-247.745	36.4**
Transversal	ND	P	0.06	5.00**	1.998	-152.563	38.2 (*p*=.068)
		PV	0.12	9.76***	2.585	-205.263	39.7**
	D	P	0.17	13.42***	2.137	-138.90	32.5*

		PV	0.11	9.27***	3.04	-230.577	37.9*
Sagittal	ND	P	0.03	2.71			N/A
		PV	0.11	7.66***	2.657	-203.069	38.2*
	D	P	0.07	6.32***	1.07	-53.134	24.8 (*p*=.294)
		PV	0.10	7.64***	3.174	-241.46	38.0*

Legend: ND – non-dominant (hand), D – dominant (hand), P – proprioceptive-only and PV-proprioceptive-visual; SC - sensory condition, MT – movement type.
Level of significance: * *p*<.05, ** *p*<.01, *** *p*<.001.

4.2.3. Paired differences for P/PV sensory conditions and ND/D hand performances

Data of a paired analysis for precision and speed performance differences for both sensory conditions (P vs. PV) and both hands (ND vs. D) are presented in Table 13.

Table 13. Paired differences for P/PV and ND/D performances (Wilcoxon sign test)

		D vs.ND				PV vs. P	
MT	**SC**	**Bias/Speed**	***Z***	**MT**	**Hand**	**Bias/Speed**	***Z***
Frontal	P	LL	-0,535	Frontal	ND	LL	-0.740
		D	-5.595***			D	-2.250*
		F	-0.602			F	-11.979***
		Speed	-0.915			Speed	-8.689***
	PV	LL	-5.587***		D	LL	-0.214
		D	-4.218***			D	-8.317***
		F	-2.985**			F	-12.071***
		Speed	-1.113			Speed	-8.231***
Transversal	P	LL	-2.665**	Transversal	ND	LL	-2.613**
		D	-0.191			D	-0.247
		F	-2.551*			F	-4.411***
		Speed	-2.907**			Speed	-7.838***
	PV	LL	-4.331***		D	LL	-3.495***
		D	-2.909**			D	-0.413
		F	-3.541***			F	-2.178*
		Speed	-6.919***			Speed	-8.693***
Sagittal	P	LL	-2.247*	Sagittal	ND	LL	-3.525***
		D	-1.013			D	-10.933***
		F	-0.162			F	-2.052*
		Speed	-2.816**			Speed	-9.277***
	PV	LL	-0.212		D	LL	-5.032***
		D	-1.411			D	-11.261***
		F	-1.363			F	-2.016*
		Speed	-3.228***			Speed	-9.058***

Legend: SC – sensory condition: P – proprioceptive-only; PV – proprioceptive-visual; ND – non-dominant and D – dominant hand correspondently; LL – line length, D – directional (bias), F – formal (bias). Level of significance: * *p*<.05, ** *p*<.01, *** *p*<.001.

This is information complementary to the previous quadratic regression analysis in order to see if the inflection ages found for different hands or sensory conditions are statistically equal or not. Thus, analysing those differences that were confirmed to be statistically significant (Table 13) and applying them to the quadratic regression analysis and ages found to be inflection points (Tables 1-4), no significant statistical differences exist between ND vs. D hand performances in precision and speed for variables:

1) in frontal movement: formal bias in P-test, line length in P-test and speed in both sensory conditions (P & PV);
2) in transversal movement: directional bias in P-test, and
3) in sagittal movement: directional and formal biases in both sensory conditions (P & PV) and line length in PV-test.

As far PV vs. P paired differences in fine motor precision and speed are concerned, no statistical differences were found for the following variables:

1) in frontal movement: line length in both hands, and
2) in transversal movement: directional bias in both hands.

In sagittal movement type all variables for precision and speed were statistically different for PV vs. P sensory conditions of test.

4.2.4. Age and sex differences in hand symmetry/asymmetry

With respect to the coherent performance (symmetry of motor lateralization) in size precision (LL) of dominant and non-dominant hands (Table 14), the lowest correlations correspond to the 12-17 age subgroup, where the significant moderate correlations were obtained only under the P test condition in frontal and transversal movements, and only in PV test for women in sagittal movement.

In directional bias (D), in frontal movement, women and men performed both with significant correlations between dominant and non-dominant hands in P-test and 12-17 age subgroup. In ages 18-29 and 65-95, the significant level in hand symmetry was reached only by women in P-test and frontal movement; whereas in men, it was in 30-64 group for the same test conditions. In frontal movement and PV-test, the significant correlation in hand performance was observed in men in 12-17 and 30-64 age groups. In transversal movement, the significant correlations were found in women, of a negative sign, in P-test and 30-64 age group; and in men in P-test and 65-95 ages. In PV no significant correlation was observed in directional bias neither of both sexes, nor in transversal or in sagittal movement types. In P-test test and sagittal movement, the hand performance correlations were significant in women in all age groups except 30-64, and in men, only in ages 65-95 (Table 14).

In formal bias, significant correlations were observed in fewer cases: in PV-test only in women of 65-95 years old in transversal movement, and in 12-17 years old in sagittal movement. In P-test, they were found in men, in frontal movement and 18-29 years old group; and in transversal movement, in 12-17 and 18-29 age groups. Women performed with statistically significant correlation between both hands in P-test, in frontal and transversal movements and 65-95 age group.

As for symmetry in hand performance in speed, the correlations were high and significant for a majority of variables, not having reached the significant level in correlation. In transversal movement type, in both sexes and both sensory conditions; also in men performance in sagittal movement and PV-test (12-17 age group) and in women performance in transversal movement and P-test (12-17 age group). For four observable variables, the highest significant correlations were observed in speed and size (LL).

Table 14. Paired correlations for precision and speed between ND and D hands

Mov. type	TC	Bias type & speed / Sex	Age							
			12 – 17		18 – 29		30 – 64		65 – 95	
			F	M	F	M	F	M	F	M
Frontal	P	LL	.50	.56**	.81***	.74***	.89**	.63***	.89***	.87***
		D	.58*	.48**	.73**	.18	.36	.47***	.63*	.01
		F	.35	-.07	-.14	.34*	.31	.09	.62*	.15
		Speed	.96***	.90***	.91***	.96***	.99***	.99**	.93***	.96***
	PV	LL	.38	.32	.46	.19	.77*	.29*	.37	.68*
		D	.14	.39*	-.01	.13	.39	.26*	.09	.12
		F	-.45	.23	-.14	.00	.16	-.19	-.12	.02
		Speed	.97***	.94***	.92***	.89***	.99***	.96*	.88***	.94***
Transverse	P	LL	.08	.55**	.68**	.45***	.90**	.51***	.66**	.78**
		D	.03	-.03	-.42	.13	-.77*	.00	-.04	.60*
		F	.17	.48**	.34	.29*	.32	.04	.67**	.16
		Speed	.35	.89***	.93***	.88***	.68	.90	.89***	.64**
	PV	LL	-.09	.33	.67**	.49***	.96***	.28*	.08	.24
		D	-.06	.18	.33	.15	.66	-.20	.11	-.20
		F	-.12	.15	-.28	.28	.15	.04	.73**	.36
		Speed	.92***	.88***	.88***	.81***	.58	.84	.90***	.82**
Sagittal	P	LL	.46	-.03	.80***	.62***	.94***	.57***	.78***	.88***
		D	.58*	.22	.64*	.26	.21	.19	.65*	.84***
		F	-.47	.04	-.02	-.20	-.22	.21	.37	-.45
		Speed	.98***	.95***	.93***	.47**	.93***	.96*	.95***	.80**
	PV	LL	.69*	.24	.13	.02	.73*	.28*	.00	.61*
		D	-.02	-.02	.37	-.28	-.24	.25	-.01	.29
		F	.73**	.04	-.13	.16	.11	.08	-.51	.39
		Speed	.95***	-.06	.92***	.90***	.93***	.97*	.95***	.77**

Note: TC – test condition; M – male, F – female; level of significance: * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$.

Regarding paired differences between D and ND hands fine motor performances, represented in Table 15, in size reproduction (LL) women performed differently in P-test and sagittal movement in 12-17 age group, whereas men did so in transversal movement for the same age group (12-17). In PV-test, LL was performed differently by each hand in women of 12-17 years (frontal movement), whereas in men the difference was observed at statistically significant level for the other three groups for the same movement. Men also performed it differently in transversal movement in ages 12-17 and 30-64 (Table 15).

In directional bias, the significant differences between dominant and non-dominant hands were observed: in P-test at ages of 12-17, 18-29 and 30-64 in men (frontal movement) and at age of 65-95 in women (transversal movement), and in PV-test at ages 18-29 and 30-64 in men (transversal movement). In formal bias, the hand performance was different in the following cases: in P-test, at age 12-17 in men (transversal movement), and PV-test, at age 12-17 in men (frontal movement) and at age 12-17 in women (transversal movement) (Table 15).

In speed, performance between the two hands was different, in P-test: at age 12-17 in women (frontal movement) and 65-95 in both sexes (transversal movement). In PV-test, the velocity was different at age 65-95 in men (frontal movement); at ages 12-17, 18-29 and 65-95 in both sexes (transversal movement), and at age 12-17 in men (sagittal movement).

Table 15. Paired differences for precision and speed between ND and D hands

Mov. type	TC	Bias type & speed / Sex	Age							
			12 – 17		18 – 29		30 – 64		65 – 95	
			F	M	F	M	F	M	F	M
Frontal	P	LL	-0.45	-0.20	0.59	1.04	0.08	0.08	-0.53	0.83
		D	0.04	2.48*	0.30	3.08*	1.84	4.60***	1.81	1.06
		F	-0.67	-0.98	-0.46	0.14	1.28	1.66	-1.75	0.42
		Speed	-2.29*	-1.21	0.78	0.44	2.35	-2.21	-1.14	-1.69
	PV	LL	2.37*	1.70	1.08	3.44***	1.80	-2.01*	0.36	3.22**
		D	-0.64	-0.16	-0.89	-2.61*	-0.95	-2.48*	0.05	-0.50
		F	-0.25	2,47*	-1.10	1.43	-1.60	1.70	1.88	1.54
		Speed	-0.60	1.28	0.78	0.19	1.76	-0.78	-1.32	-2.41*
Transverse	P	LL	1.28	2.46*	1.04	0.66	0.97	1.61	-1.17	0.95
		D	1.16	1.23	-1.21	-0.31	-0.11	-1.22	2.77*	-0.74
		F	0.47	-2.82**	0.23	-1.39	-0.19	-1.50	-1.88	-1.12
		Speed	0.63	-0.92	-0.05	0.42	1.10	-0.74	-2.41*	-2.76*
	PV	LL	1.34	2.71*	1.25	0.01	-0.12	2.61*	1.93	1.23
		D	-0.46	0.07	0.00	-1.22	-0.59	-1.41	-1.11	-0.96
		F	-2.24*	-1.73	-1.21	-1.27	-1.22	-1.94	-1.50	-0.28
		Speed	-3.96**	-3.90***	-3.67**	-2.73**	-0.17	-1.80	-2.30*	-2.76*
Sagittal	P	LL	2.20*	-0.03	0.08	0.91	0.24	0.92	0.15	-0.20
		D	-0.81	-1.44	-0.65	-0.19	-0.37	0.13	-0.62	0.96
		F	0.92	0.91	-0.43	-1.31	-0.62	0.88	0.41	-0.72
		Speed	-1.51	-0.72	0.15	0.63	0.13	-0.24	-1.81	0.02
	PV	LL	-0.56	1.00	0.00	-0.54	-1.58	0.03	-0.61	-0.02

D	-0.91	-1.33	-1.27	-0.20	0.68	0.33	0.54	0.61
F	0.27	0.91	0.58	-0.45	-1.76	-1.70	-0.16	-0.88
Speed	-0.93	-2.06*	0.02	-0.71	0.21	0.38	-2.00	-0.41

Note: TC – test condition; M – male, F – female; level of significance: * $p \le .05$, ** $p \le .01$, *** $p \le .001$.

4.2.5. Correlational analysis between precision and speed

The results of Spearman correlational analysis between precision and speed performance[3] for all ages are represented in Table 16 for raw data that take into account the direction of deviation for precision and for absolute precision (with absolute data). Analysing the raw data (taking into account the direction of movement), the following significant correlations between fine motor performance and speed were found:

1) In frontal movement type:

- for LL (line length) bias in PV-test for both hands, with a negative sign (greater line length LL, quicker was done);
- for D (directional) bias in PV-test the correlation reached a statistically significant level only in doninamnt hand (a negative sign correlation);
- for F (formal) bias in P-test and both hands (positive sign correlations).

2) In transversal movement type:

Moderate correlations with a positive sign were found for P-test: in LL bias (dominant hand) and weak correlations with negative sign, for D and F bias types.

3) In sagittal movement type:

Significant correlations of a negative sign were found in PV-test in LL and F bias types (dominant hand) and in P-test in LL and D bias types (non-dominant hand) (Table 16).

[3] Since participants were only instructed to be precise, their speed performance reflects individual differences in velocity focusing on accuracy of movements.

Table 16. Spearman correlations between precision (size and spatial deviations) and speed performance

			Bias type (bipolar tendencies, raw data)						Bias type (total precision, absolute data)					
Speed			LL		D		F		LL		D		F	
MT	Hand	SC	PV	P	PV	P	PV	P	PV	P	PV	P	PV	P
Frontal	ND	PV	-.31***	-.13	.09	.01	.13	.32***	.07	.11	-.28***	.06	-.19*	.32***
		P	-.21*	.05	.06	.03	.09	.25**	.05	.05	-.22**	.04	-.30***	.25**
	D	PV	-.24**	.09	-.18*	-.15	.06	.38***	.12	.21*	-.01	.30***	-.01	.38***
		P	-.14	.01	-.14	-.10	.07	.29***	.02	.12	-.05	.24**	-.05	.29***
Transversal	ND	PV	.14	.12	-.16	-.01	-.06	-.27**	.12	.19*	-.19*	.27**	.04	.43***
		P	.10	.13	-.19*	-.06	-.00	-.26*	.02	.18*	-.15	.26**	.00	.48***
	D	PV	.17	.27**	-.11	-.03	.09	-.12	.08	.31***	-.14	.23**	-.19*	.26**
		P	.08	.46***	.02	-.26**	.04	-.17*	.02	.32***	-.10	.23**	-.19*	.31***
Sagittal	ND	PV	-.03	.24**	-.13	.23**	-.03	-.17	-.12	.30***	-.18*	-.00	-.01	.18*
		P	-.06	.31***	-.06	.35***	-.05	-.04	-.16	.18*	-.15	.11	-.04	.17
	D	PV	-.22**	.14	.01	.10	-.25**	.10	.01	.35***	-.27**	.04	.02	.32***
		P	-.10	-.03	.01	-.04	-.10	.16	-.01	.21*	-.20*	.12	.01	.23**

Legend: SC – sensory condition: P – proprioceptive-only; PV – proprioceptive-visual; ND – non-dominant and D – dominant hand correspondently; LL – line length, D – directional (bias), F – formal (bias) and T – time (speed); significance level: * p<.05, ** p<.01, *** p< .001.

Regarding fine motor precision without taking into account the direction of bias (absolute data), we can see no statistically significant correlations in size (LL) in PV-test whereas in P-test the significant correlations were found in transversal and sagittal movements types; all of them were of positive sign. As for spatial deviations, (D – directional and F – formal biases), all significant correlations in PV-test were of a negative sign between precision and velocity performances, and in P-test, of a positive.

CHAPTER 5. DISCUSSION AND STUDY LIMITATIONS

In general there is scant scientific research about comparison of fine motor behaviour in men and women, and less about sex*age interaction dependences. Current research provides a full description of both motor precision and velocity performances in both sexes and their changes dependent on age. Although the differences in time performance did not reach statistically significant level, some differences in sex in precision were observed. As per age-dependent trends, similar to sex differences in alpha diapason width, described in the Introduction part of this Chapter, presented by Bazanova (2008) and colleagues, the age-dependent changes were almost in parallel in our study (Fig. 4.2.1, 4.2.2 and 4.2.3).

Mergl and colleagues (1999) observed greater variability in handwriting performance in size in women, while in this study the size (line length) variability performance alternated more widely in women or men or equally, depending on movement type, hand and with most effect of age factor (especially in P-test condition). Age group affected the variability in precision changes in size (LL) even within the same sex subgroup. For example, in men, LL (transversal movement, ND hand and P-test) changed in different age groups as follows: 1) 51.64±17.00 mm (12-17), 2) 30.18±7.17mm, 3) 34.63±7.24 mm and 4) 96.91±70.55 mm; whereas in women for the same bias and test conditions, variability was greater in 12-17 and 30-64 age groups and less in 65-95 (raw data): 1) 49.40±27.84 mm, 2) 30.78±6.60 mm, 3) 46.74±21.20 and 4) 77.91± 38.78. For the same test conditions, at old age (65-95), in D (directional bias) men performed with higher variability: -16.99±47.14 mm vs. 9.60±29.62 mm, whereas in F (formal bias), the situation was the opposite (with greater variability in deviation observed in women): -16.94±13.49 mm vs. -24.66±29.62 mm. Thus, there is no unique pattern in precision and variability of behaviour of men compared to women, but different tendencies depending on test conditions and age.

As far as the Kring and Gordon study is concerned, women as *externalizers* and men as *internalizers*, which would correspond the fine motor behaviour with movement inside or outside, especially relating to directional movement in transversal movement (Mira, 1958), there some observations in our study to mention here. First of all, the only negative correlation was found between both hands performance in P-test in transversal movement and directional error type, statistically significant in women at age 30-64 (r= -.77, p<.05). However, if this trend is to be confirmed in future replicative studies, it would mean that more are internalizing women are by their biological nature (non-dominant hand and right hemisphere for right-handers) that should be related to female hormones (since the correlation was observed in the middle age group and only in women, not in men), the more externalising will they show in their adaptive behaviour (dominant hand and left hemisphere for left-handers) or vice versa.

Analysing the directional bias in transversal movement type, which corresponds to behavioural trends towards the external world (extra-tension) or the internal world (intra-tension), we can see that men were slightly shifted toward intra-tension (movements towards inside) in age group 65-95 years old in ND hand (P-test). Average values were left (or inside) shifted in men: -16.99±47.14mm vs. 9.60±29.62 mm; whereas in D hand, women had the left bias more pronounced compared to men: -22.94±31.33 mm vs. -8.57±28.37 mm. At age 30-64 they performed quite similar to men in their average group value, though they had grater variability in performance: -0.15±37.95 mm vs. 0.24±12.85 mm in ND hand and 2.04±21.98 mm vs. 2.94±11.08 mm. In 18-29 age group, in ND hand, the parameters were quite similar: -1.37±11.57 mm in women vs. -1.67±10.72 mm in men; whereas in D hand, the tendency to Extratension in average value is more pronounced in women: 5.69±14.17 mm vs. -1.06±10.45 mm. A similar situation was observed at 12-17: 10.77±20.79 mm in women vs. 2-94±21.33 mm in men (ND hand) and 2.03±16.39 mm in women vs. -3.13±15.11 mm in men.

As per MANOVA results with Bonferroni correction, the significant differences between both sexes' performances were found:

a) *In line length size (LL):*

- in frontal movement type:
    1) in ND hand and P-test: women performed better than men compared to the model (40 mm): 41.09±2.43 mm vs. 43.83±1.82 mm (F=6.24, p=.013),
    2) in ND hand and PV-test: men performed better than women compared to the model: 41.00±0.44 mm vs. 39.31±0.58 mm (F=5.80, p=.017),
    3) in D hand and PV-test: men were also precisier than women: 39.33±0.42 mm vs. 38.06±0.55 mm (F=4.26, p=.040);
- in transversal movement (LL):
    4) in ND-hand and PV-test men performed better than women: 42.67±1.86 mm vs. 47.17±1.67 mm (F=15.68, p<.001),
    5) in D-hand and PV-test men also showed better precision in size: 41.16±1.16 mm vs. 44-88±1.55 mm (F=15.80, p<.001);

b) *in Directional bias (D)*:
    6) in transversal movement, ND hand and P-test men performed with better precision compared to women: -1.92±2.55 mm vs. 5.07±3.39 mm (F=5.53, p=.020);

c) *in Formal bias (F):*
    7) in frontal movement, ND-hand and PV-test women performed better to men: 0.06±0.19 mm vs. 0.34±0.14 (F=6.50, p=.012).

In speed performance, women performed slower than men in the 65-95 group age in the majority of the observable variables (in all except in PV-test and dominant hand in frontal and transversal movements types); however, these differences did not reach a statistically significant level in MANOVA analysis, which did not show any significant effect of sex on speed performance at all. Also no statistically significant age*sex interaction in speed differences were found between performances for both sexes.

In precision, sex*age significant interactions were found in size performance (LL) in the following test conditions (only in PV part of test):

- in frontal movement:
  1) ND hand: in the 30-64 age group: 41.77±3.01 mm in men vs. 38.67±2.97 mm in women (F=7.51, p=.008),
  2) D hand:
     a) at age 12-17: 41.70±2.71 mm in men vs. 39.70±2.62 mm in women (F=4.96, p=.032),
     b) at age 30-64: 37.02±3.02 mm in men vs. 46.96±12.57 mm in women (F=18.96, p<.001),
- in transversal movement:
  3) ND hand: at age 30-64: 37.02±3.02 mm in men vs. 46.96±12.57 mm in women (F=27.62, p<.001), and
  4) D hand: at age 30-64: 36.01±3.78 mm in men vs. 47.17±8.35 mm in women (F=43.31, p<.001).

The above mentioned results of age*sex significant interactions showed that the main sex differences were performed at the middle age (30-64) and PV-test and both hands. Moreover, in frontal movement men overperformed in their average value for line length both women's results and the model size (40 mm) in their group average value, whereas in transversal movement type, the situation was the opposite, where women did so.

MANOVA results with Bonferroni correction revealed age factor to have a significant effect on fine motor behaviour, especially in line length (LL) precision (for all test conditions, p<.001, Table 5) and speed (T) (for all test conditions with p≤.022, except ND hand and PV-test in sagittal movement). In directional (D) bias, age was a significant factor in three test conditions: D hand and P-test in transversal movement ($p<.001$) and PV-test in sagittal movement: in ND hand ($p=.003$) and D hand ($p=.033$). In formal (F) bias age effects were significant mainly in frontal movement type: in ND-hand and P-test ($p<.001$), in ND hand and PV-test ($p<.001$) and in D hand ($p<.001$) and P-test ($p<.001$); also it was significant in transversal movement, D hand and P-test ($p<.001$) (Table 5).

Post-hoc analysis showed that the eldest group performed significantly more poorly than to the other ages in all test conditions (Table 1 and Table 7); however they underperformed LL in PV-test in frontal and sagittal movement types, and overperformed in P-test and transversal movement (in both sensory conditions). Thus, at age 65-95 y.o. men performed line length as 37.38±4.25 mm and 34.33±3.41 mm by ND and D hands, women as 34.86±3.13 mm and 34.46±4.11 mm by ND and D hands in frontal movement in PV-test, whereas in P-test LL was in men 65.65±36.93 mm / 60.96±96±35.68 mm in ND/D hands and in women, 48.29±14.75 mm / 49.51±18.43 mm in ND/D hands respectively. In sagittal movement the situation was a similar one. In PV-test, men performed line length as 33.09±3.36 mm / 33.11±3.43 mm (ND/D hands) and women as 32.74±3.01 mm / 33.46±3.17 mm (ND/D hands) and in P-test, the LL was correspondingly 50.30±27.98 mm / 51.13±23.21 mm in men and 48.43±17.34 mm / 47.94±18.83 mm. In transversal movement, in both sensory conditions LL was outperformed with worse average value and greater variability in men in ND hand and P-test: 96.91±70.55 mm (Table 1).

The youngest group (12-17 y.o.) in some cases also performed more poorly LL in precision compared to other age groups: in frontal movement, ND-hand and PV-test with 30-64 age group; in transversal movement and P-test, with 18-29 age group (in both hands), and in sagittal movement, ND hand and PV-test with 30-64 age group. Moreover, in transversal movement and PV-test (both hands), each of four age groups performed differently from other age groups at statistically significant level (Table 7); therefore these test conditions could play a role of a discriminatory marker for belong to any of these age groups.

In directional bias (D), 65-95 age group showed poorer results compared to all the other age groups only in transversal movement and P-test (only in dominant hand); whereas the age group of 30-64 was worse in sagittal movement, ND hand and PV-test than all the other groups; and in ND-hand only than 65-95. In formal bias (F), the precision performance was poorer in 65-95 group compared to all the other age groups: in frontal movement and P-test (in both hands) and PV-test (ND hand) and in transversal movement and P-test (both hands). In sagittal movement the differences in F bias precision did not reach statistically significant level.

As far as speed performance was concerned, again the elderly group performed worse (more slowly) than all the other age groups in frontal movement and P-test (both hands) and in PV-test (ND hand) only than 12-17. In transversal movement they were slower than all the other age groups in dominant hands (both sensory conditions); whereas in non-dominant hand the difference reached a statistically significant level with age groups of 18-29 and 30-64 in P-test and with 18-29 only in PV-test. In sagittal movement, 65-95 group was significantly slower in P-test (both hands) with middle ages (18-29 and 30-64) and in ND hand and PV-test, with 12-17 and 18-29.

It had been suggested that intact proprioception is necessary for the rapid processing of visual feedback during movements (Balslev, Miall & Cole, 2007), so that deterioration in proprioception would lead to poorer performance under vision conditions (in our case, in PV-test). In this study, higher quantity of significant differences in speed performances of the eldest group (65-95) compared to the other age groups was shown in P-test and dominant hand:

- in frontal movement: 3 significant differences (from all the other groups) in P-test vs. the 1 only in PV test in ND hand and 3 (P-test) vs. 3 (PV-test) in D hand;
- in transversal movement: the proportion of statistically significant differences of 65-95 age group from the others in P/PV sensory conditions were respectively as 2/1 in ND hand and 3/3 in D hand;
- in sagittal movement: the proportion of statistically significant differences of 65-95 age group from the other in P/PV sensory conditions were respectively as 2/0 in ND hand and 2/2 in D hand.

As far as symmetry (significant paired correlations) between non-dominant and dominant hands was concerned, the highest and majority of correlations was observed in speed, followed by line length (LL), with least and fewer correlations in formal (F) bias. In precision, the lowest correlations for majority of test conditions are observed at age of 12-17. Nevertheless, the correlational pattern has a more complex pattern and differs not only in various age groups, but also depends on sex and test conditions. Thus, at age of 12-17 in transversal movement type, in women no significant correlation was observed between ND and D hands in precision, whereas in men, it was in LL and F bias in P-test. In sagittal movement type of the same age group, no significant correlation in hand symmetry was observed in men subgroup, whereas in women it was shown in D bias and P-test and LL and F bias in PV-test. Analysing all data, for the majority of the observable variables in precision the significant correlations were shown in P-test compared to PV-test: in frontal movement – 14 correlations in P-test vs. 5 in PV; in transversal movement, the proportion was as 12 to 5, and in sagittal movement 10 to 5. This fact (and for the majority of them the correlations were greater in P-test) proves that in P-test condition the manual symmetry is higher than in PV-test (with vision). Another conclusion from the previous observations described above is that at earlier ages (12-17) for majority of variables in different test conditions the symmetry is weaker compared to other ages.

Regarding the asymmetry between both hands performances, the results of age-dependent differences study are consistent only to some extent with the hypothesis of shifting to ambidexterity with aging, since some variables were found with a statistically significant difference between dominant and non-dominant hands in the oldest group (65-95). Thus, in fine motor precision, in LL (line length) performance, men performed better in non-dominant hand compared to dominant in frontal movement and PV-test: 37.38±4.25 mm vs. 34.33±3.41 mm (p<.01); in D (directional) bias, the only statistically significant difference in both hand performaces was observed in women (at age of 65-95) being in transversal movement and P-test (p<.05): 9.60±29.62 mm (ND hand) vs. -22.94±31.33 mm (D hand) with greatest shift to left (Intra-tension in their dominant hand). In F (formal) bias, no statistically significant differences were found in the elderly age in either sex.

As for the other age groups, women performed LL differently at age 12-17 in favour of dominant hand in frontal movement and PV-test (p<.05) and in sagittal movement and P-test (p<.05). Men performed LL differently in frontal movement and PV-test, being precisier in D hand at ages 18-29 (p<.001), at 30-64 (p<.05) and in ND hand (p<.01) at 65-95; in transversal movement P and PV sensory conditions in favour of D hand at 12-17 years old (p<.01), and PV-test at 30-64 years old in favour of ND hand (p<.01). In directional (D) bias, men performed better in ND hand in frontal movement and P-test in all age subroups except in 65-95 y.o. (p<.05, p<.05 and p<.001), whereas in PV-test the D hand was more precise in middle age groups (18-29 and 30-64, p<.05). In formal (F) bias, ND hand performed better in men in frontal movement and PV-test at 12-17 years old ($p<.05$) and D hand was better in precision in transversal movement and P-test for the same age group ($p<.01$). Women performed better in favour of D hand in transversal movement and PV-test at 12-17 years old ($p<.05$). Thus, the precision of dominant hand compared to non-dominant did not have a stable pattern within specific sensory conditions (P or PV), just as Goble and Brown (2008) had found errors to be smaller in nonpreferred left arm in proprioceptive matching tasks errors and in preferred right arm during the visual matching tasks. In this study the patterns were more complex and depended on age and also sex.

As far as the significant differences in velocity performance of both hands are concerned, faster performance of the dominant hand was shown only in women at age 65-95 years (transversal movement type, PV test condition), which was consistent with the results of Stern and colleagues (1980) that the right hemisphere (left hand) works faster. In the other case, ND hand was significantly faster:

- in women at 12-17 y.o. in frontal movement and P-test ($p<.05$),
- in men at 65-95 y.o. in frontal and transversal movements and PV-test ($p<.05$),
- in both sexes at 65-95 y.o. in transversal movement and P-test ($p<.05$), in transversal movement and PV-test at 12-17 and 18-29 years old.

As far as the correlations of precision * speed were concerned, this exploratory analysis showed that LL (line length size) had correlations with velocity of performance in PV-test only in raw data (that take into account the sign of deviation). All significant correlations were of negative sign, meaning that the quicker the participants trace the line model, the greater line length is, and vice versa (Table 16). In frontal and sagittal movements in raw data all significant correlations in PV-test are of a negative sign, and in P-test, of a positive; the same tendency is observed in the absolute precision data (deviations without taking into account sign). In transversal movement type in D (directional) and F (formal) biases, the correlations in P-test were of a negative sign resulting in the opposite pattern to the other cases, whereas in P-test condition the realationship was of positive sign, meaning that the faster participant performed it, the less error (bias) there was. Thus, for absolute precision, less deviation (error) was correlated with slower speed in PV-test and faster in P-test.

The hypothesis of quadratic distribution of fine motor precision (with highest fit for line length and speed) was confirmed in this sample and helped to calculate the approximate ages (for different movement types and sensory conditions) in the self-reported healthy population, which is a new exploratory contribution in the aging process and developmental psychology. For line length precision and the frontal moment types, the inflection points were from 22 to 26 years old; in transversal movement they ranges were 31/35 for ND/D hands in P-test and 45/47 for ND/D hands in PV-test, while in sagittal movement they were found as 10/19 for ND/D hands in P-test (in PV the quadratic function was approximately lineal due to very small as zero coefficients in age^2). Inflection points in speed and some of presion corresponded to middle age, which was consistent with results both in neurological brain maturity and motor precision studies described in the introductory part.

This study has two limitations that should be considered. Firstly that the health state was self-reported, not checked by any other means (as self-reported, participants were not diagnosed by any neurological or motor impairment disease, or any other illness since they were controlled for medication intake also). However, the test itself is a kind of measure of neurological state, since participants had to start at the same point (although the previous trials of incorrect pointing were not registered by the software sine the data started to be registered after reaching the correct point as by given instruction), so it could be seen if the person had severe problems with it or other qualitative changes in performance in the proprioceptive part of test. In our previous study with Parkinson's patients (early stage of disease, medication on /state off), concerning LL (line length) precision, only men of Parkinson's group traced a line length greater at statistically significant level in the dominant hand (right) and frontal movement type in PV-test condition (Gironell, Liutsko, Muiños, & Tous, 2012). However, in this study, in the frontal movement type, PV condition, the oldest groups performed line length smaller in PV condition, and greater in P test condition compared both to the model line length (40 mm) and the other group's performances.

Another important limitation is that we had smaller sample for the older ages. It is a question of time, since the test consists in individual application and general disposition of healthy volunteers (especially if healthy and still working). Nevertheless this gap can be covered by future research. Due the fact that life expectancy and even retiring age is varying in different countries, the information obtained by the current research is more reliable for Spain and countries with similar above-mentioned indicators.

Since there is limited improvement in cognitive performance due to cognitive training in older people (Martin, Clare, Altgassen, Cameron, & Zehnder, 2011), maybe one of the alternative method to maintain their cognitive level is to keep their proprioceptive function in better condition for as long a period as possible. This task can be attained by maintaing physical and psychological health: practicing exercises that improve or maintain proprioception (tai-chi, relaxation and stretching, yoga or simply dancing and singing, playing musical instruments), healthy diet, acquiring emotional self-control (effective managing of emotions); and anything that allows a healthy life style to be maintained.

This exploratory analysis revealed important findings about the age when proprioception worsens due to natural aging processes in the healthy population. It is important to take into account inflection points as periods of change, in order to prevent the risk of possibly related pathological states. The ages found for P-test can be related to the appearance of diseases such as Parkinson's. The age 45/48 found as inflection points for PV condition (transversal movement) is consistent with the age when a start of decline was reported (Sturnieka, Georgea, & Lord, 2008). Moreover these ages can be taken into account during age-group comparison (especially young vs. elderly), since up to a certain middle age both precision and velocity in fine motor precision and proprioceptive acuity is not optimum, and for this reason the age groups should be split carefully to reduce the noise due to maturation processes. The age-dependent polynomial can be split into two parts, simplifying up to two linear regressions: one, with a negative sign up to the age performance by the found inflection points (as a maturity and skills acquiring process); and another one, with a positive sign, after this point (changes that can be attributed mainly to aging natural process or age-cohort differences).

Important piece information found by this study was that ages corresponding to inflection points for proprioception condition were "younger" for majority of test conditions for fine motor precision and for velocity, compared to performance with vision. This finding can suggest that proprioceptive sense starts to deteriorate earlier than vision, or can even cause subsequent negative changes in vision as a compensatory effect of extra load on vision. People who lost their proprioception controlled their movement mainly cognitively and by vision (e.g. Ian Waterman case shown in the BBC documentary film "The man who lost his body"). If proprioception is crucial for automatic locomotor behaviour and spatial orientation, then if it deteriorates, performance should be compensated by other senses, principally by vision and cognition: to direct more attention at controlling the action and thus indirectly affecting the cognitive performance. Maybe for this reason, little or no effects were found of cognitive exercises in maintaining cognitive performance with aging; and persons with professional training that involved to cognitive functioning (pilots and architects, for example) had shown age-related trends in parallel to those who had not (Salthouse, 2006). Moreover, the sensory-sensoriomotor variables were found to be statistically good predictors of age-based differences in general intelligence in the older population (Linderberger & Baltes, 1997). Another example of proprioception's effect on cognition (distribution of attention), especially in double-task performance, is reflected by work of Ingram and colleagues (Ingram *et al.*, 2000). Also it was found that older adults devoted more cognitive resources to dual-task performances compared to the younger group (Lövdén, Schellenbach, Grossman-Hutter, Krüger, & Lindenberger, 2005), and they perturbed their balance (trunk-angle variability) (Shellenbach *et al.*, 2010).

Thus, the deterioration of proprioception by aging can also provoke a decrease of performance in cognitive tasks due the additional cognitive effort required to maintain balance and gait. However, the performance in the proprioceptive condition is more variable compared to that adjusted by vision, and this dispersion in performance also follows the quadratic function, being greater at their extremes (young and old persons), showing higher variability in performance in these age groups. The ages found to be as inflection points could also be related to different developmental stages. The majority of them coincide with a period known as "midlife crisis" (corresponding to 35-45 years old) (Kulikova, 2004), which was observed but not yet experimentally proven.

Proprioception is important both for maturation and aging processes and can influence speed of individual progressing age-related development on the one hand, and was found to be related to brain plasticity, on the other hand, reflecting the unit of body-mind states. For example, music positively affects proprioception and creates new nerve connections in the brain (Wan & Schlaug, 2010), and is used to recover neurological patients after suffering stoke (Schauer & Mauritz, 2003), while musical education was found to be a precursor of higher intellectual predisposition and performance in children (Glozman & Pavlov, 2007). Our previous studies showed negative significant correlations between proprioceptive imprecision and academic performance (Liutsko, Muiños, & Tous, 2012) and level of visual memory in some movement types (Liutsko, Tous, & Muiños, 2012). Moreover Baltes and Lindenberger (1997) emphasises the importance of attending to the phenomena of cognitive aging from the point of common factors for the sensory and intellectual domains; Goble (2010) underlined a crucial role for proprioceptive feedback in the reorganization and subsequent recovery of the nervous system, and van Hedel and Dietz (2004) pointed to optimization of the other proprioceptive inputs in the elderly. Furthermore positive effects on balance (dynamic postural control) were reported in elderly individuals who regularly practised low-energy proprioceptive physical activities such as soft gymnastics or yoga (Gauchard, Jeandel, Tessier, & Perrin, 1999).

CHAPTER 6. CONCLUSIONS

Both Mira y Lopez (1923) and Luria (1932) expressed in their works that motor function reflects the structure of the hidden psychological processes. Sechenov (2013) wrote that behind each thought the movement is hidden. In Shibutani's words (cited in Miroshnikov, 1971), a personality should be determined in terms of its potential actions, and not in the obvious behaviour. Thus, motor behaviour allows observing the latent behavioural tendencies and intentions, peculiarity of psychological processes, and is an important part of global personality evaluation. For these reasons, modern tendencies embrace all assessment approaches in order to achieve a complete picture of personality. More research work nowadays deals with body-mind connections and how action can affect cognition. In Berstein's theories about action development the following basic premises were expressed (Latash & Turvey, 1996, p.435):

- *movements are the units of action;*
- *movements are either the results of CNS commands or reflexive;*
- *movements are more likely to be repeated when they become associated with pleasurable feelings or outcomes;*
- *the repetition of movements, leading to changes in the frequency of given movements, is the central mechanism in action learning.*

When a subject is trained to pursue a specific movement, the practice produces vigorous circulation of impulses in corticoperipherical loops related to this movement. Repeated practice results in an increased efficiency of synaptic transmission of these loops.

Thus, motor control forms of being one of the basic describing components of individual differences and can moreover be a bridge for further formation of personality. In their turn, individual differences can explain the variability of motor behaviour and can be of possible explanation of systematic drifts observed by Rantanen and Rosenbaum (2003) who mentioned that there were no explanational studies for it. This work by the described results of experimental findings contributes to understanding the individual sex and age-dependent differences.

The main contribution and results of this PhD dissertation were the following:

I. *Synthesis on the topic "Proprioception and its role in health and quality of life"*

Literature review together with results obtained from the exploratory work here emphasise on the importance of proprioceptive sense for a quality and healthy life at all levels (physical, emotional and cognitive) and how it can influence the acquiring of good customs and habits and used in the educational process or in both coaching and self-re-education for personal constructive evolution. There it was also given the summarised scheme that included the major ways of keeping proprioception at optimum levels with help of multiple factors shown in the integrative model (Chapter 1).

II. *Age and sex differences in proprioception based on fine motor behaviour*

While sex was shown to have statistically significant differences for fine motor precision for some observable variables, it was not significant in speed performance. In precision the following variables in various test conditions were performed differently by men and women:

a) line length (LL) – in ND hand and P-test (frontal and transversal movement types): women performed better in frontal movement (41.09±12.72 mm) compared to men (42.25±15.34 mm); whereas in transversal movement the contrary situation was observed: higher precision in men (41.06±27.20 mm vs. 51.84±31.89 mm);
b) directional bias (D) – in ND hand and P-test (transversal movement) with higher precision in men (-1.15±19.06 vs. 5.07±25.03), and
c) formal bias (F) – in ND-hand and PV-test (frontal movement) with higher precision in men (-0.38±0.75 mm vs. -0.64±1.44mm).

Moreover, the significant age * sex interactions were found in LL: all of them in PV-test, for both hands (frontal and transversal movement types). Thus, sex differences were statistically significant at age 12-17 for the variable of LL in D-hand and frontal movement (F=4.96, p=.03), being in average precision better in men compared to the model length of 40 mm, though with the greater variability (41.11±14.03 mm vs. 35.77±6.83 mm) and at age 30-64 in both hands of frontal movement (F=7.51, p=.008 for ND hand and F=18.96, p<.001 in D hand) and transversal one (F=27.62, p<.001 for ND hand and F=43.31, p<.001 for D hand correspondingly). Here men achieved the their best precision in frontal movement, with average values of 40.20±8.98 mm in ND hand and 40.12±7.29 mm in D hand. The women subgroup slightly underperformed LL in frontal movement (38.88±12.96 mm and 38.72±10.62 mm in ND and D hands respectively). In transversal movement, men underperformed LL in average group value (34.63±7.24 mm and 32.94±8.80 mm in ND and D hands), while women overperformed it (46.74±21.20 mm and 43.25±14.66 mm in ND/D hands).

Age was the most important factor in both fine motor precision (especially in size, LL) and velocity performances. The precision was more different for the eldest age-group (65-95), followed by the youngest group (12-17), and in some cases, such as in LL (PV-test and transversal movement type, in both hands) each of four age groups performed differently from others. Thus, the fine motor precision in size (LL) under these test conditions can be regarded as a marker for belonging to each of age group.

III. *Symmetry/asymmetry in hand performance and sex differences in proprioception based on fine motor behaviour*

Paired correlational analysis between both hands performances showed more symmetry in P-test and with the magnitude (or appearance) of symmetry with age was observed not for all, but for the majority of variables and test conditions. The exceptional situation, due to negative sign relationship compared to the rest that all had positive signs, was observed in directional bias of the female subgroup (30-64), in transversal movement type and P-test (r=-.77, p<.05). This finding was not confirmed in other studies (Belarus) and thus cannot be considered for the time being as a stable sex difference (at least at multicultural level), requiring future replicative studies. The highest correlations were found in size performance (LL), followed by the order of magnitude of values for spatial errors: directional and formal ones.

Paired differences (asymmetry) results did not prove a clear preference in precision and/or velocity of fine motor behaviour for a non-dominant hand (right hemisphere) in P-test and dominant (left hemisphere) in PV (with vision) condition. Thus, the statistically significant difference in hand performances in precision varied depending on sex, age, variable and test conditions. Most of the significant differences were found in the oldest and youngest age groups (12-17 and 65-95). In speed performance, in all the cases with statistically significant difference except in the one (in women of 65-95 in transversal movement and PV-test), non-dominant hand was faster compared to dominant one.

IV. *Precision * speed relationship*

In raw data, the relationship between precision and speed in PV-test in all test conditions for all observable variables, also in directional and formal biases in P-test in transversal movement was found to be of negative sign, whereas in the other P-test conditions it was of positive sign. In absolute precision (without taking into account the sign), for all significant correlations, the relationship in PV-test was of negative sign and in P-test of positive sign, meaning that less error corresponded to slower speed of tracing in PV-test and faster in P-test.

V. *Age-dependent differences in line length performance (precision and velocity) related to proprioceptive feedback and sensory integrative function of proprioception and vision feedback*

In this study the quadratic function was shown to be the best fit for LL performance in the studied movement types: frontal and transversal (both for precision and speed). The inflection points (where the ANOVA analysis and coefficients of age^2 were appropriate) revealed the age of changes for proprioceptive fine motor behaviour and proprioceptive-visual behaviour: for precision in P-test in transversal movement – 35 years old for non-dominant hand and 31 years old for dominant; in PV-test – 45 and 48 years old for non-dominant and dominant hands correspondingly. For frontal movement type, the corresponding ages for changes were 26 years old for dominant hand and P-test, and 23 years old for the other movement x hand conditions. In sagittal movement, the appropriate inflection points were shown in P-test as 10 years old in ND hand and 19 years old in D hand.

For D (directional) and F (formal) biases, the quadratic functions were of poorer or no fit. The highest R^2_{adj} in directional bias was of 0.15 that corresponded to 47 years as an inflection point. In formal bias the highest R^2_{adj} were observed in P-test as 0.18 in ND hand (32 years old) and 0.24 in D hand (38 years old) in frontal movement and as 0.20 (25 years old) in ND hand in transversal movement.

Concerning velocity of performance, as in LL the quadratic polynomial was also the best fit for age-dependent differences. The critical ages for speed performance, as inflection points of the quadratic polynomials for changes, were found within ranges of 33-38 years old for P-test and both movement types, and 36-40 years old for PV-test.

The important general finding for fine motor control that these age-dependent differences showed, that these inflection points were "younger" for P-test condition. Other non-direct findings (that were not initially hypothesised) revealed peculiarities of fine motor function behaviour and this can help to find further aptitudes in data analysis techniques (more homogeneous groups in sex and age would bring more normalized data, for example); also to improve other techniques of data transformation for robust statistical analysis without losing significant information. Finally, this research opens other doors for improving the methodology of proprioceptive diagnosis that can be helpful both for research and practical applications.

CHAPTER 7. APLICATION OF FINDINGS AND FUTURE RESEARCH

Earthly life passed before the half,

I found myself in a dark forest ...

(From "Divine Comedy" by the famous Florentine Dante Alighieri)

This thesis represents a synthetical review of literature (with use of sources in their original versions in English, Spanish and Russian) that permits a broad overview of an important topic, “proprioception”, and its related concrete studies of age, sex and individual differences based on fine motor behaviour. Since the proprioceptive sense in psychology is still little known, both theoretical and experimental studies will help to cast light on its deeper understanding. Proprioceptive sense can be regarded as a key to individual differences that can be taken into account in therapeutic, medical, psychological and educational work. Due to specificities of proprioceptive behaviour, we can see the predisposition and sensibility of people to stress and subsequent adaptation, reaction to medical treatment and general behavioural aptitudes that are reflected in habits, customs and skills. Moreover, changes that occur in proprioceptive feedback can provide information about whether the therapeutic work and rehabilitation have positive effects.

The information on findings described in this work is important in order to have a “starting point” for comparing further specific research results. In addition, the “inflection” ages found can help to make a suitable division into age subgroups in order not to lose information or distort the results. Moreover, this information can help in preventive programs on these crucial points of age, so that people get through them with fewer problems or smooth any midlife crisis that might arise.

Sex differences and sex*cultural differences in other preliminary studies are also important for differential psychology and individual differences and in generally for aging (developmental) processes. They could explain the differences in application of retirement in different countries. For example, the age for retirement in Spain is the same for men and women while in Belarus and Russia, women retire earlier. Another aspect of individual differences in proprioception is based on fine motor performance due to "extracortical" activities, as per Luria definition of cultural internalisation, to which or we could add the results of modern research as embodiment of cultural knowledge.

On the other hand, the exploratory results in research shown here can provide a series of practical applications. First of all, it is important to highlight the interrelationship between different levels of organism organization or body-emotion-cognition triad shown via different studies with use of the proprioceptive method (DP-TC) of the Mira y Lopez Laboratory (University of Barcelona) together with other projective or verbal techniques reported in this work. The current tendency in health supports a combined (or complex) view of the problems (physical and psychological ones and taking into account individual differences) that helps to provide higher quality and more effective treatments and preventive measures for human health issues.

Another important point and conclusion from age-dependent studies is that in order to help both to maturation and preparation for cognitive work in the pre-school period, as well as to retention of cognitive abilities and physical health much longer in the face of natural aging effects, the proprioceptive system has to be maintained at optimum level. It is also important in order to obtain more effective results in preventive, therapeutic or educational work, to take into account sex differences resulting in a more individual approach to people.

Proprioceptive state also reflects the emotional intelligence and general emotional state of the person, and appears to be important in brain plasticity functions. For this reason, some kind of physical exercise (yoga, Pilates, stretching and balance), music, dancing and work with rhythm could bring positive results on proprioceptive state that will bear positive fruits at cognitive level as well. The importance of chemical balance is also an important issue, so nutrition or taking medicaments can affect proprioceptive state.

The proprioceptive diagnosis is a non-verbal method and can give good complementary information about what a person thinks about himself (reflected by verbal tests) and reveal more dispositional behaviour. One of the most important things for future research is to distinguish the individual evolutionary level and approach in order not to confuse "deficit as maladaptation" and "deficit as a source of strength", for as was emphasised by Vigotsky, *"a defect is not only a minus, a deficit, or a weakness but also a plus, a source of strength" and that "along with a defect come combative psychological tendencies and the potential for overcoming the defect" (*cited in Zinchenko & Pervichko, 2013).

In order not to confuse "abnormalities" (such as deficit or illness) with similar-looking other states of positive "abnormalities" (high creativity, for example) other research is needed to investigate whether pathological states can be distinguished from talented or creative states on the basis of proprioceptive fine motor behaviour. This is an important topic that could help to distinguish between "negative" and "positive" abnormalities without prejudice to the last group. It is also incorrect to think that the highest motor precision is the best variant, since the literature review shows that people with somatoform disorders have very acute proprioception. Some errors exist and their peculiarities depend on bias type, hand use and movement type, as was seen from the descriptive statistics provided in this work. Although it is maybe clearer that normality is determined by mean values, it is quite difficult to make judgements about "abnormalities" in order not to put all of them to the pathological category (that happened frequently with incorrect diagnoses). We do not treat intellectual people as suffering from "abnormally" high IQ, although until now there has been no methodical distinction between pathological and "gifted" levels in emotional aspects, for example.

Nevertheless, in spite of the fact that most scientific work concentrated on clinical and pathological issues, some studies exist that cast light on this problem of seeing "duality". Thus Dabrowski (1972) pointed out that psychoneurosis is not an illness; and in gifted person's over-excitability was much more frequently observed compared to the normal population (retrieved from The SENG Newsletter, 2001). Manzano, Cervenka, Karabanov, Farde, Ullén, and Rustichini (2010) from the Karolinska Institute reported that the dopamine system of healthy, highly creative people is similar to that found in people with schizophrenia; and many (but not all) Parkinson's patients treated with dopamine-enhancing drugs developed artistic talents. Thus, the impulsivity that in some patients caused gambling, overeating and sexual excitability (Hinnell, Hulse, Martin, & Samuel, 2011), or even "Othello" syndrome (Cannas, Solla, Floris, Tacconi, Marrosu, & Marrosu, 2009), in others was channelled into artistry. As a doctor declared, people who after L-dopa treatment started painting were very happy about that change (American friends of Tel-Aviv University, 2013).

Shelley, Peterson, and Higgins (2003) discovered that decreased latent inhibition was associated with increased creative achievement in high-performing individuals. As for the link or similarity between madness and creativity, Shelley says: "It appears likely that low levels of latent inhibition and exceptional flexibility in thought might predispose to mental illness under some conditions and to creative accomplishment under others." (*University of Toronto*, 2003). For example, during the early stages of diseases such as schizophrenia, which are often accompanied by feelings of deep insight, mystical knowledge and religious experience, chemical changes take place in which latent inhibition disappears (Shelley, Peterson & Higgins, 2003). "We are very excited by the results of these studies," says Peterson. "It appears that we have not only identified one of the biological bases of creativity but have moved towards cracking an age-old mystery: the relationship between genius, madness and the doors of perception." (*University of Toronto*, 2003).

Dr Kazimierz spent 45 years piecing together the evolutionary growth of the human psyche. In his opinion (Dabrowski, 1972), all things that are normally considered as potential risks of neurosis or psychosis, such as suffering, loneliness, self-doubt, sadness, inner conflict and all the feelings that we have not learned to live with, we normally do not appreciate and frequently reject as destructive and completely negative; however, they are in fact symptoms of an expanding consciousness. This growth can occur just after some significant crisis, caused by any of external and/or internal causes. In the process of loosening of the stable psychic structure, accompanied by symptoms of psychoneuroses, reality becomes multi-levelled. Psychoneurotic symptoms should be embraced and transformed into concerns about human problems of an ever higher order. Without passing through very difficult experiences, such as psychoneurosis and neurosis, we cannot understand human beings or realize our multidimensional and multilevel development toward higher levels. (Dabrowski, 1972). Moreover, in his opinion:

The propensity for changing one's internal environment and the ability to influence positively the changing of one's internal environment and the ability to influence positively the external environment indicate the capacity of the individual to develop. Almost as a rule, these factors are related to increased mental excitability, depressions, dissatisfaction with oneself, feelings of inferiority and guilt, states of anxiety, inhibitions and ambivalences – all symptoms which the psychiatrist tends to label psychoneurotic. Given a definition of mental *health as the development of the personality, we can say that all individuals who present active development in the direction of a higher level of personality (including most psychoneurotic patients) are mentally healthy.*

(Dabrowsky, 1964, p.112)

Intense psychoneurotic processes are especially characteristic of accelerated development in its course towards the formation of personality. According to our theory accelerated psychic development is actually impossible without transition through processes of neuroses and psychoneuroses, without external and internal conflicts, without maladjustment to actual conditions in order to achieve adjustment to a higher level of values (to what "ought to be"), and without conflicts with lower level realities as a result of spontaneous or deliberate choice to strengthen the bond with a reality of higher level.

(Dabrowsky, 1972, p.220)

The model of future progress can be shown as a tendency to move towards "positive" abnormalities, as expressed by Lutsko (1995) (see Figure 5.1). For this reason, as well as due to the more stressful lives humans have, it is important to provide the relevant help to persons who are undergoing critical situations in their lives in order to prevent them from falling down, also it is not necessary to return to their previous level if the consequences can be used for personal growth and qualitatively constructive changes.

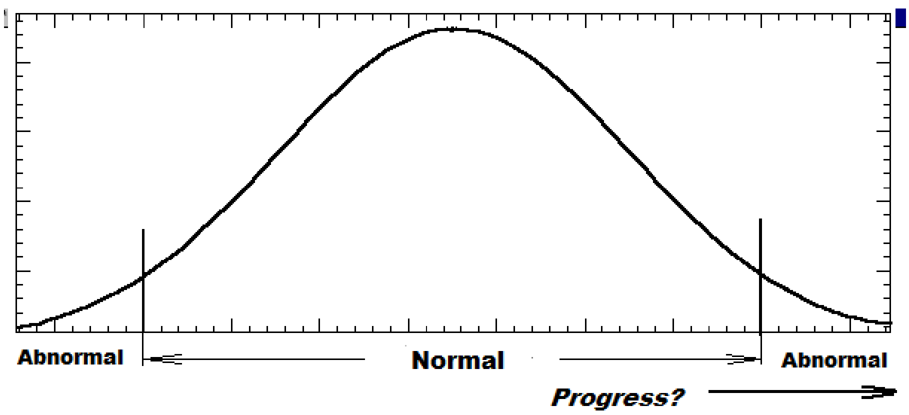


Figure 5.1. Progress trend and Gaussian distribution of normality (adapted by the author, *source*: Lutsko, A., 1995).

The contribution of this work is to understand individual differences in order to make therapeutic and educational help more effective and better adjusted to those differences. It is important to properly consider and interpret well the results of tests in order to avoid “overdiagnosing” or to be used in proper therapeutic intervention. Ages found by quadratic regressions to be inflection points, correspond to the peakes of higher maturation and to some extent confirm the ages from the developmental and general psychology (from 35 to 45) that are described as ages of “mid-life crisis” (cited in Kulikova, 2004). This period is characterised by higher sensibility, a new perception of time, deep changes in personality and professional/social life and a general re-avaluation of life’s values (reviewed by Kulikova, 2004).

The successful resolution of the crisis means the transition to adulthood, to certain wisdom of life, forms of human desire for efficiency, caring about the next generation, and the thought of his contribution to what is happening on the ground. Mid-life crisis can easily become a springboard for a new take-off, the so-called second peak of vitality. It contributed to the emergence of many great people. Gauguin began his career as an artist at age 39, after being sacked from his work at a bank. Goethe's journey to Italy, undertaken between 37 and 39 years, completely changed his state of mind and had an impact on his work. Michelangelo at the critical age changed the style and quality of his work. And we know many such examples - of scientist or businessmen going into politics, others beginning to engage in charity, and some in art, etc. *(Middle life crisis*, 1998). Jung regarded the mid-life crisis as a period in the psyche’s transformation, when people looked inward and thought about the meaning of their own lives. Although the period around 40 years is accepted by the majority of scientists as an adult crisis, no experimental work confirms it so far done (Ippolitova, 2005). Considering the proprioceptive sense as an intrinsic basis of personality and individual differences, this work confirms the mid-life crisis ages for a majority of variables, although each observable variable contributes to specific features and thus we can observe the other developmental (organism's maturation) periods in adults also.

If we again compare the personality structure to an atomic model, then it is similar to that we can observe at the atomic level of elements (especially the radioactive ones), when some input of extra energy (or collision with another atom) can provoke the instability of electrons that move in one orbit and can then pass into another orbit, thus changing the quality of the atom (Figure 5.2).

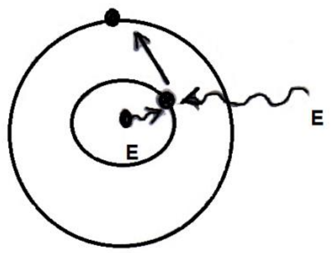


Figure 5.2. Change in the structure after energy input.

"Critical periods" are the stages that vividly display the transition from the lower level of system functioning to the higher one. The main task of a psychologist is to reveal how an adult (or a child), ill or in good health, approaches a critical stage, how the person negotiates the crisis, and which external and internal mental determinants allow the emergence of new psychological formations.

(Zinchenko & Pervichko, 2013).

Actually the hieroglyph for "crisis" in Chinese reflects its dual future or perceptional perspective: one, and the best known, is "a catastrophe", although the second meaning of "a new opportunity" also exists. It is a crucial issue in order to help people to get qualitatively through their developmental crises instead of breaking away from them on the previous level or "labelling" them as "pathological ones" for the rest of life. Future research is required in order to distinguish between two levels – pathological, or distortional one and qualitative change with expansion of conscience – see schematic diagram of both processes in Figure 5.3. On this question the integrative scheme or total skeleton of the personal profile in proprioceptive diagnostics could be very helpful in order to evaluate the whole bias balance compared to the normally centred. If the extremes are "balanced" and offset each other that would mean that a person is "balanced", and changes or therapeutic interventions are only required if any of these extremely high or low indices cause destructive behaviour or endanger the health of that person or others in the environment.

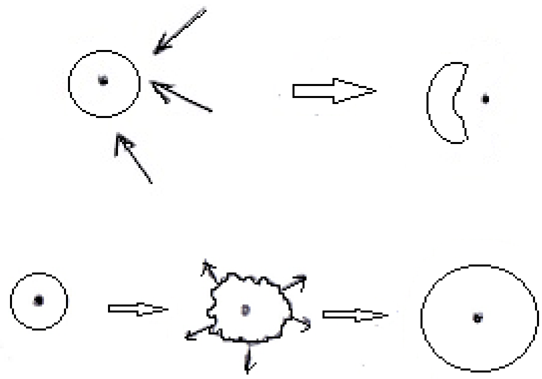


Figure 5.3. Different possible ways of change a) collision and distortion; b) expansion and evolution.

However, any change in one pole can cause changes in another pole (not necessarily of the same dimension). The importance of this work consists in establishing the initial orientative picture that describes the general healthy population. These data are informative not only for understanding proprioceptive fine motor behaviour and its sex and age-dependent differences, for these data also serve as some kind of “coordinates” to be compared with other data specific to both pathological or outstanding groups of people, as well as an orientation basis when interpreting the individual profile. For example during investigation and practical work with participants in Belarus (2012) there were several cases confirming similar tendencies: those participants who had very restrictive and controlled parental behaviour developed a Submission pole higher than 67% of the population, and also had (possible compensatory element) another higher extreme pole of Variability in behaviour. And one of the participants in this “subgroup” with similar biographies had another specific quality: extremely high Inhibition (as DP-TC test showed). The hypothesis after analysing his profile was that his parent figure (possibly mother as the key figure in child education for this historical culture) may have been more dominant, more energetic in terms of “quickness” and could crate by her own specific individual characteristic frequent situations of pressure and acceleration of her child’s behaviour. As a result, since he also had a profile with high Submission pole, this boy tried to follow the requirements of his “accelerated” and “energetic” mother, but his own nervous system had no dispositional element for it – high inhibition – , and that could be a reason why he was stuttering (he also participated in this study just for his own curiosity). During the subsequal interview he confirmed the hypothesis of his mother behaviour.

Another important issue of future research work lies partly in discrimination between “negative” and “positive” abnormalities in order not to overdiagnose pathologies where they do not exist; is to see how our physical health is linked to psychological state beyond work done already. So far, several studies already exist about mind-body connections. Thus, Velasques and colleagues (2011) described abnormalities in motor control related to psychiatric disorders (Alzeimer’s disease, autism spectrum disorder and schizophrenia). However, although they found the sensorimotor integration function to be important in motor control, it was still not clear whether the deficits found were contributed to by a defective central processing or abnormal peripheral sensory input, and recommended further studies to find the causes. Researchers from Indiana University suggested that postural control may be a core problem of bipolar disorder (the patients had problems with balance – they swayed more when their eyes were closed), and that could be a new potential target for treatment (Bolbecker, Hong, Kent, Klaunig, O'Donnell, & Hetrick, 2011). However, it is always important to see the consequences of all types of treatments. For example, one bipolar patient claimed (personal communication) that after starting the pharmacological treatment prescribed by her psychiatrist her creativity was suddenly reduced and she was not able to perform with the same effectiveness at her job (she was a designer), and her chief was not content with this change.

Who knows, if outstanding personalities with well-known historical biographies were treated for the pathologies they had or were suspected to have, maybe they would not be so outstanding then? They would simply be returned from "positive" or constructive abnormality to a general "normality" level. Then perhaps the world would not have such personalities in the qualities they demonstrated themselves, such as Nobel prize-winning mathematician John Nash (suspected to have paranoid schizophrenia), painter Van Gogh and physicist Einstein (both suspected to have bipolar disorder), writer Andersen (dyslexia), poet Edgard Poe (signs of suicidal behaviour), composer and musician Bethoveen (suspected to suffer from bipolar disorder), although his physical deficit (hearing loss) is well known and did not stop him creating magnificent compositions. Most of genious were reported to be more nervous and/or have cyclothymic (affective) disorder (Hare, 1987). Famous and talented writer Pushkin, who did not speak until five years old, had periods of melancholy (that could be observed as depressions) seen from his lyrics, especially in the autumn period. Dostoevsky suffered from epilepsy and impulsive behaviour (spending a lot of money at the casino). Fine motor precision is maybe a more important quality for technician profiles, such as engineers, while for a creative person it may not actually be so be beneficial.

Another important thing is that pre-reflexive behaviour should not be disregarded. Many time this automatic reaction, due to it quickness (before the consciencious reacts) helps to survive in extreme situations. Many biographical cases were reported about adults, who without thinking about their own lives saved others. Without it our world would not have heroes. Sometime it even happens without any skilled automatic habit and without any previous knowledge about the consequences of action, working as an instinct. As was the case when five-year old Danila from Buriatia (Russia, news taken from TV) saved his older sister who had fallen through the broken ice into a river. *"He instinctively grabbed her hood with the strongest muscles of the human body - jaws. So, standing on all fours and his milk teeth clenched, he stood for half an hour until help arrived."* (Skvortsov, 2010).

Concerning pathological – normal - outstanding behaviour, more experimental and scientific studies are needed in order to understand the complexity of behaviour and individual differences, and proprioception would be an informative base for it. In general, body-mind links were shown with typical experiments from the medical universities program when the heart placed separately from the organism lives and works at its own rhythm, while inside of the organism that cycle can be interfered with due to neurochemical changes or breathing patterns. Robles and Peralta (2006) from the University of Granada described in their research and experimental work how different personalities (not adaptive) can have more risk of suffering cancer or heart attacks (insults). For this reason the modern tendencies of psychological work are based on emotional intelligence, humanistic and positive thinking.

The famous psychologist and psychotherapist Sinelnikov (2009), in his book "Love your disease dearly. The way to get healthy by perceiving the joy of life", shares with his own practice results turning the aptitude to any illness instead of “fighting with” to “understanding” what this illness is trying to tell us about the problems we have. Conventional medicine deals more with consequences and facilitates the symptoms rather the real causes of illness. And the most important aspect is to find these causes and eliminate them. Thus in his therapeutic work (Sinelnikov used subconscious information during hypnoses), he often found time the real reasons for somatic illness lay in incorrect behaviour (including emotions and thoughts) towards others or described internal family conflicts (being exposed to incorrect behaviour of parents caused the illnesses in their children also). Although it is not pure scientific research, nevertheless in order to conduct any research it is good to be an acute observer and to observe real life. Any illness report to us the consequences of individuum or environmental-link-to individuum conflicts or affects, only we cannot have the whole picture since we cannot read thoughts and emotional manifestations and can sometimes be confused (Punset claimed that somatic reactions can be the same for the person who just committed a crime or just made love). For this reason the diagnoses or conclusions about personal behaviour should be taken with caution, and his/her real morality or intentional level will play an important role.

Thus, personality models in DP-TC need to be extended and complemented by behavioural sublevels, ranging from negative (destructive) to positive (constructive) ones. For example, high behavioural variability at its low (or negative) level could bring problems with organisation and planning, some kind of chaotic behaviour; however, in its positive aspect, it could be natural, creative and spontaneous behaviour that allows the person to be “in the flow”. Impulsivity has negative qualities such as gambling, impulse eating, and positive ones such as creativity and artistry. High emotivism, however, is different if we deal with love or hate. And so on. The scientific investigation in proportion deals much more frequently with the negative side of psychological qualities, while the other, positive pole needs to be investigated in order to understand and gain the whole picture.

The basic foundations of Vygotsky's cultural-historical concept, in its application to the field of studies of clinical psychology (Vygotsky's work "The Historical Meaning of the Crisis in Psychology") reveal the principles of postnonclassical epistemology, the idea of selectivity of perception and the notion of selective interchange with the environment, where these qualities of self-adaptation, self-tuning, and self-organization are considered most essential for a self-developing system:

The mind selects the stable points of reality amidst the universal movement. It provides islands of safety in the Heraclitean stream. It is an organ of selection, a sieve filtering the world and changing it so that it becomes possible to act. In this resides its positive role—not in reflection (the non-mental reflects as well; the thermometer is more precise than sensation), but in the fact that it does not always reflect correctly, i.e., subjectively distorts reality to the advantage of the organism.

(Zinchenko & Pervichko, 2013).

LIST OF ABBREVIATIONS

L and R – left and right hands correspondently

ND o index nd and D or index d – non-dominant and dominant

*Movement types (*MT*):*

F – frontal

T – transversal

S – sagittal

Bias types:

D – directional

F - formal

LL – line length

ΔLL – line length variability

*Sensory test conditions (*SC):

P – proprioceptive only

PV – proprioceptive-visual

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ANNEX 1. Publications and studies related to Mira y López' MKP (in chronological order):

Also the majority of publications were done in Spanish and Portuguese, however, there works in English, German, French, Italian, and Russian. The greatest part of works cited here were taken from references in Mira, A. (2002).

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ANNEX 2. Short history of the of Mira y Lopez's laboratory evolution (Personality, Psychological Assessment and Treatment department, Faculty of Psychology, University of Barcelona)

Up to this moment, the evolution of the Mira y Lopez laboratory can be divided into three main periods from the time when revision and digitization had been started by Prof Josep Maria Tous Ral in 2000:

1st stage: Introduction of the scanning of graphical results performed by participants with use of the pen-pencil method of Mira y Lopez (Tous & Viade, 2002), as an introduction of Myokinetic Psychodiagnosis, Revised and Scanned (PMK-RE, abbreviated from Spanish name "Psicodiagnóstico Miokinético Revisado y Escaneado").

2nd stage: The advanced version, the PMK-RD test (or Myokinetic Psychodiagnosis, Revised and Digitalized) comprised the use of special digitalized tablet on which the kinematic tracings were performed.

3d stage: Appearance of DP-TC (Proprioceptive Diagnosis of Temperament and Character), with digital technique (with use of touch screen), which was applied for measuring proprioceptive kinematic hand movements. The term "proprioceptive" is used, since a fine motor behaviour in proprioceptive condition (without external feedback correction of graphical movements or seeing the active hand position) stands at the base of this method. Its description follows below.

ANNEX 3. Brief review of recent studies carried out at the Mira y López Laboratory

A3.1. Individual differences in proprioception reflected in mnemonic activity (visual memory), emotional intelligence, and academic performance.

This study was carries out on a sample of ordinary and special school pupils (N=63) with use of both Proprioceptive Diagnostic (PD) and the Rey-Osterrieth Complex Figure (ROCF) for memory results in order to check how proprioception and memory were related. There were found to be significant negative medium correlations between Directional Frontal (DF), Sagittal Directional (DS) and Sagittal Line Length (LLS) movement types of proprioceptive diagnostics (PD) and Immediate memory of ROCF; and between SLL movement type of PD and Delayed Memory and Recognition of ROCF. All significant correlations were found for non-dominant hand (Liutsko, Tous & Muiños, 2012).

Another research performed here was to see the relationship between proprioceptive biases in fine motor precision test (Proprioceptive Diagnostic) and both memory and academic performance. The results revealed that some proprioceptive indicators were linked to academic performance (grades) with memory as a moderator; however, there were found such proprioceptive bias types as secondary deviation, that had been related directly and only to academic performance and was not affected by visual memory. This indicator was more closely related to emotional regulation (Liutsko, Muiños & Tous, 2012).

A3.2. Proprioceptive differences based on fine motor precision in Parkinson's patients vs. group of age and sex matched control

Patients of Parkinson's disease demonstrated the higher rigidity (less variable behaviour) in PD (Tous, 2008) based on fine motor precision test in medication-off state compared to the matched in age and social level participants of control group (Gironell, Liutsko, Muiños & Tous, 2012). Dr Latash also commented from his own studies observations that patients of Parkinson's disease in spite the fact that they have later tremor, their movements are more limited in spatial terms (from private conversation during Motor Control conference in Wisla, Poland, 2012).

This was the first study where the division into sex subgroups resulted in additional information that could not be seen when only the whole group analyses were applied. This information could provide biological individual sex differences in Parkinson's patients both in the further development of the disease, as well as in the response to medical treatment.

A3.3. Changes in proprioceptive feedback information based on fine motor performance in dual-task test

This was a pre-study of checking whether there exist any differences in proprioceptive feedback bases on fine motor precision in performances in single (only motor) and dual task (motor + cognitive). Ten participants were voluntary students of average age of 20 years old. Wilcoxon sign test for differences showed a statistically significant difference in size (line length) performance with tendency to increase in double (with counting numbers backwards) task (Liutsko, Segura & Tous, 2013). This finding tells us about changes in the Inhibition-Excitation balance of the nervous system under additional (cognitive) charge towards to Excitability, even in young people. Further studies among elderly population (over 60 years old) are required.

A3.4. Individual differences in fine motor performance precision in Arabic immigrants to Spain, and cultural differences (Spain and Eastern Europe)

In this research there participated 26 immigrants to Spain from Morocco and 30 Spanish residents matched in age and educational level. ANOVA results showed several statistically significant differences in fine motor precision performance between the two cultural subgroups: in transversal movement (Lineograms) and in line length variability performance (Parallels). These differences could be attributed to the habit of direction of writing (especially in transversal movement) and to an adaptive mechanism due to immigration. After splitting and controlling the sex differences within each cultural subgroup, more information was found that had not been detected in the whole group comparison due to compensatory effects of both sex performances. For example, in directional error of non-dominant hand and sagittal movement the sum precision of both sexes did not differ by the average value of Spanish group. However, within the Morocco subgroup men performed much better than women (F=4.86, p=.037): 12.13±7.90 mm in men and 20.64±11.80 mm in women correspondingly). That was the only statistically significant difference between men and women in emigrants of Arabic culture, whereas no significant differences between sexes, for fine motor performances were found in the Spanish cultural subgroup (Liutsko & Tous, in preparation for publishing).

Moreover, another comparative study between four cultural subgroups (East Europe, Spain, immigrants to Spain from Morocco and Latin America) revealed some significant cultural and sex differences in proprioception based on fine motor precision (communication Liutsko & Tous, 2013).

A3.5. Correlational analysis between DP-TC and other somatic (BMI) indicators, time perception and verbal tests (Rosenberg's self-esteem, Big Five bipolar test and Eysenck EPQ) in both sexes (Belarus sample)

In this international study the participants from Belarus took part and went through the series of tests: proprioceptive (DP-TC), verbal (Rosenberg's self-esteem, Russian adaptation of the Japanese version of Big Five with bipolar dimensions and Russian adaptation of Eysenck EPQ test) and time perception test (to estimate when one minute had passed). Moreover, additional information about body size (weight and height) was gathered to calculate body mass index (BMI) and the question to name the favourite colour without thinking much (which can be related to emotional state). Since all the main techniques are well-known, the only thing that needs to be described (just to see the difference and similarity with the original version of NEO-PI-R of McCrae Costa), are the dimensions of Big Five test translated from Russian, as given below (inverted scales):

1) Extraversion – Introversion
2) Affection/affiliation – Isolation/independence
3) Self-control – Naturalness
4) Emotional Instability – Emotional Stability
5) Friskiness – Practicality.

As for the qualitative variables, colours, they were codified by numbers, beginning from 1 for white, 2 for yellow, etc… going from the light colours to the dark ones finishing with black. Some specific names of colours (only a few) such as "colour of body" or "colour of sea water" were codified to a similar colour form the standard classification or given the mean number, e.g. "sea water" could correspond to between green and blue integer numbers.

The correlational analysis was done for all observable variables to see the relationship between somatic, projective and verbal characteristics; again they did not reflect the same information. Sex-dependent differences were checked here and how ethical or consciousness aptitude (groups were done as per Lie scale of EPQ test) changed the relationships between somatic and verbal variables.

The results revealed different correlational relationships in both sex and "Lie" subgroups compared between them and with the whole groups; however some of them were retained across subgroups, resulting only in a change of correlation magnitude. For example, Time Perception (TP) was negatively correlated with body mass index (BMI) in men (r=-.42*), and this correlation was confirmed in only the Liars' subgroup[4] (r=-.59*). While for men BMI showed the only significant correlation with TP, in women BMI, a part of negative significant correlation with TP but of lesser magnitude (r=-.29*), also had negative correlations with DSnd – directional sagittal movement of non-dominant hand (r=-.26*) (DP-TC) and E (r=-.29*) (EPQ test) and positive correlation (r=.27*) with variability of line length ($\Delta LL = LL_{max} - LL_{min}$). In adult women, who have one of the parameters of BMI, height as a fixed one, the dependence of BMI that was found would reflect the change in weight. Thus, decreasing in women weight, as per above described results, depends on hetero-activity (aggressiveness direction towards others, as per sagittal movement shown) – actually the optimum portion of such hetero-aggressiveness would not mean violence, just assertiveness. On the other hand, women who had higher self-aggressiveness would increase in their mass (weight). This movement type (directional and sagittal), as per DP-TC psychological dimension descriptions means a balance between submission and dominance. Persons with high submission also could suffer from

[4] Here we have to take into account that in the groups with high values in Eysenck scale Lie a part of persons who wants to appear to be "socially good", could be met the persons who really did not performed any "bad" thing due to their high ethical and moral behaviour.

others due to the low level of their contra-activity (assertiveness or aggressiveness) and they preferred to suffer and hide inside themselves. For this reason, it is not surprisingly that they unconsciously act by strengthing the protection level and increasing the mass of skin in order to make a "greater" wall between the person and the environment. Moreover, the increasing of weight was related to Introversion in behaviour (Eysenk's test) and more flexible, spontaneous or impulsive behaviour (DP-TC) that could be related to more passive lifestyle for the first and impulsiveness in eating without restraint for the second. This is just an example of possible interpretation of how the individual qualities of different levels of behaviour can be interrelated.

In female subgroup the majority of correlations were related to ΔLL (DP-TC test). The proprioceptive variables had medium and low, but all significant, correlations with all five dimensions of Big Five verbal test. Additionally, this variable (ΔLL) in non-dominant hand negatively correlated to time perception, and in dominant hand positively to body mass index. Formal deviation (which is related to emotional self-control and maturity) in dominant hand of frontal movement of DP-TC positively correlated to scale of Colour (and both variables are indicators of emotional state. Directional deviation in dominant hand and transversal movement (Intra-tension / Extra-tension dimension of DP-TC) positively correlated with value obtained by Rosenberg Self-esteem test, meaning that the more Extra-tensive person is (more oriented towards the external world), and he/she has higher self-esteem (verbally assessed). Finally, directional bias in non-dominant hand in sagittal movement (DSnd) was positively weakly but significantly correlated to both BMI and Extroversion of EPQ in women. After splitting the female subgroup into Non-Liars and Liars, in the first one, all statistically significant correlations that were observed in proprioceptive test vs. verbal, were found with Extraversion scale of Eysenck EPQ (r=.48) and Extraversion of Big Five (r=.49), also with Self-Control (r=.53) and Dependence (r=.50) from Big Five adapted to Russian bipolar scale version. While in the Liars subgroup (who got the False mark in Lie scale of Eysenck EPQ test), statistically significant correlations between DP-TC proprioceptive variables were related to P and N (including L scale itself) of EPQ test, Emotional Instability of Big Five, which were replicated in various proprioceptive variables at least twice. Moreover, only one moderate positive significant correlation was found with Introvertion from Big Five and negative one with Self-Esteem value of Rosenberg.

As per men subgroup, the major quantity of correlations were obtained with DSnd proprioceptive variable resulting in negative moderate correlations with TP and Fig Five dimensions such as Introversion, Independence and Emotional Stability. Directional deviation in non-dominant hand and frontal movement (related to Mood scale of DP-TC) had negative correlation with P scale of EPQ (r=-.40), while DTnd (directional bias in transversal movement and non-dominant hand) of DP-TC negatively correlated to Colour scale in men (r=-.46). These correlations between DTnd and Colour scale were replicated in both Non-Liars (r=-.81) and Liars (r=-.53) subgroups.

Unlike in women, in the Non-Liars male subgroup the negative correlations with Extraversions (both EPQ and Big Five) were found to be statistically significant. In addition, here the high significant correlations were found between ΔLLd and Colour (r=.77) and DTnd and BMI (r=.90), whereas in the Liar's subgroup the majority of significant correlations between proprioceptive variables were negative and related to Self-esteem, Colour, Independence and Practicality (Big Five), and TP (time perception). The only positive correlation was found between secondary or formal bias in frontal movement and non-dominant hand (FFnd) with P (r=.53*).

Although men and women groups had their own specific relationship between proprioceptive and verbal variables, the common tendency was observed in Liars and non-

Liars subgroups in both sexes. Concerning characteristics described by sign of correlation and to which verbal parameters they were related; it is possible to conclude that the Liars subgroup was more emotionally unstable or anxious compared to the Non-Liars one. It is an interesting and very informative exploratory research that needs more detailed study of all obtained results in the preliminary study.

ANNEX 4. Publications and conference participation of Emilio Mira y López Laboratory

Tous, J.M. and Viadé, A. (2002). Advances in MKP-R. *Psicologia em Revista*, 8(12): 95-110, [In Spanish, English summary].

Tous, J. M., Viadé, A., Chico, E., y Muiños, R. (2002). *Aplicación del Psicodiagnóstico Miocinético revisado (PMK-R) al estudio de la violencia*. [Application of revised Myokinetic Psychodiagnosis (MKP-R) to the study of violence] Comunicación. *III* Congreso Iberoamericano de Psicología clínica y Salud (Caracas, 20 – 23 de noviembre de 2002). [In Spanish]

Tous, J. M., Vidal, J., Viadé, A., y Muiños, R. (2002). Relaciones empíricas entre niveles de anticuerpos y actividad motora propioceptiva según puntuaciones en tres escalas verbales de personalidad. [Empirical relations between antibody's levels and proprioceptive motor activity as verbal scores on three personality scales] Comunicación. III Congreso Iberoamericano de Psicología clínica y Salud (Caracas, 20 – 23 de noviembre de 2002). [In Spanish]

Tous, J. M., Viadé, A., y Muiños, R (2002a). *Rendimiento en los lineogramas del PMK-R, en un grupo de tiradores de élite y un grupo de universitarios*. [Performance on lineogramas of MKP-R, in a group of elite sharpshooters and a group of university.] Comunicación. *III Congreso Iberoamericano de Psicología clínica y Salud* (Caracas, 20 – 23 de noviembre de 2002). [In Spanish]

Tous, J. M., Viadé, A., y Muiños, R. (2002b). *Componentes verbales y motores propioceptivos de la ansiedad en una muestra de universitarias*. [Verbal and motor proprioceptive components of anxiety in a sample of university] Comunicación. III Congreso Iberoamericano de Psicología clínica y Salud (Caracas, 20 – 23 de noviembre de 2002). [In Spanish]

Tous, J. M., Muiños, R., Chico, E., Pont, N., y Viadé, A. (2003). *Diferencias motoras de personalidad en presos, policías y universitarios, según el PMK-D*. [Motor differences in personality of prisoners, police and university students, according to the MKP-D] Póster. II Congreso Nacional de Psicología de la Sociedad Española para la Investigación de las Diferencias Individuales (Barcelona, 24 – 26 de abril de 2003). [In Spanish]

Tous, J.M., Viadé, A. Pont, N., y Muiños, R. (2004). Actualización del PMK y aplicaciones del PMK-RD. [Updating the MKP and MKP-RD applications]. *Revista de Psicología General y Aplicada*, 57(3): 315-326. [In Spanish]

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Tous, J.M., Viadé, A. and Muiños, R. (2006). *Structural validity of Myokinetic Psychodiagnosis Revised (MKP-R) lineograms*. Communication, *13th European Conference on Personality*, Athens, Greece, 22-26 June 2006.

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Tous J.M., Viadé, A., y Muiños, R. (2007). Validez estructural de los lineogramas del psicodiagnóstico miocinético, revisado y digitalizado (PMK-RD). [Structural validity of lineograms of myokinetic psychodiagnosis revised and digitized (MKP-RD).] *Psicothema*, 19(2): 350-356. [In Spanish]

Tous, J.M. (2008). *Diagnostico Propioceptivo del Temperamento y el Carácter DP-TC. [Proprioceptive diagnosis of temperament and character]* Barcelona: Lab. Mira y López. Department of Personality, Assessment and Psychological Treatments, University of Barcelona. Software.

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Tous-Ral, J.M., Muiños, R., Liutsko, L., and Forero, C.G. (2012). Effects of sensory information, movement direction and hand use on fine motor precision. *Perceptual and Motor Skills,* 115(1): 261-272. doi: 10.2466/25.22.24.PMS.115.4.261-272

Tous-Ral, J.M. and Liutsko, L. (2012). *Quantified differences in hand drawing precision from exteroceptive (visual) and proprioceptive versus proprioceptive feedback only*. In Books of abstracts of Moscow International Congress dedicated to the 110t anniversary of A.R. Luria's birth, p. 101. Conferences "A.R. Luria and the development of the world psychological science", "A.R. Luria and modern neuropsychology", 29th of November – 1st December, 2012. Moscow: Lomonosov State University, Psychology Department.

Liutsko, L., Tous, J.M., and Muiños, R. (2012). The effects of proprioception on memory: a study of proprioceptive errors and results from the Rey-Osterrieth Complex Figure in a healthy population. *Acta Neuropsychologica*, 10(4): 489-497.

Gironell, A., Luitsko, L., Muiños, R., and Tous, J.M. (2012). Differences based on fine motor behaviour in Parkinson's patients compared to an age matched control group in proprioceptive and visuo-proprioceptive test conditions. *Anuario de Psicología,* 42(2): 183-197.

Liutsko, L., Muiños, R., and Tous, J.M. (2012). Changes in fine motor behavior with age (based on visuo-proprioceptive and proprioceptive only feedbacks). In (Eds: Juras, G. and Slomka, K.): *Current research in motor control* , pp. 90- 96. Poland: AWF Katowice.

Liutsko, L., Muiños, R., and Tous, J. (2012). *Relación entre inteligencia emocional basada en la información propioceptiva y rendimiento académico en alumnos de secundaria.* [Relationship between emotional intelligence based on the proprioceptive information and academic performance in pupils of the secondary school]. In: Libro de abstracts [Book of the abstracts], I Congreso Nacional de Inteligencia Emocional [The I National Congress of Emotional Intelligence], 8-10 of November, Barcelona. [In Spanish]

Liutsko, L., Muiños, R., and Tous-Ral, J.M. (2012). *Changes in fine motor behavior with age (based on visuo-proprioceptive and proprioceptive only feedbakcs*). Poster and short oral presentation, the abstract published in: Books of abstracts (Eds: Slomka, K. and Juras, G.). International Scientific Conference Motor Control 2012 – From Theories to Clinical Applications, 27-29 September, 2012, Wisla, Poland, p. 47.

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Liutsko, L. and Tous, J.M. (2013). *Sex and cultural differences in proprioception based on fine motor precision*. Comunication at ISSID conference, 22-25 of July, Barcelona.

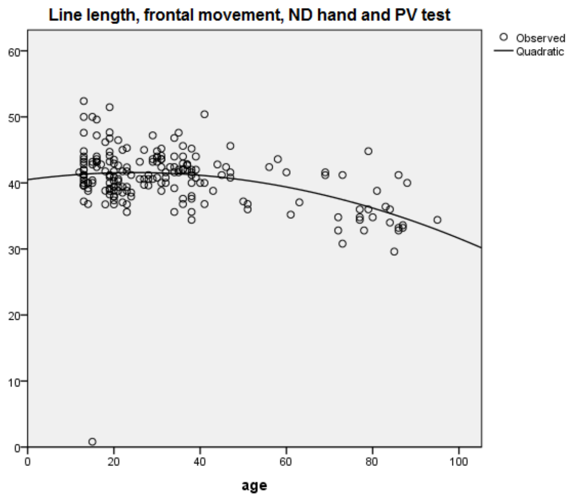
Liutsko, L., Tous, J.M and Segura, S. (2013). *Effects of dual (motor precision + cognitive) task on proprioception.* Manuscript submitted for publication and oral presentation at at summer course "4th Outdoor sports recreational activities" in Biala Podlaska (Poland), 22-28 of September, 2013.

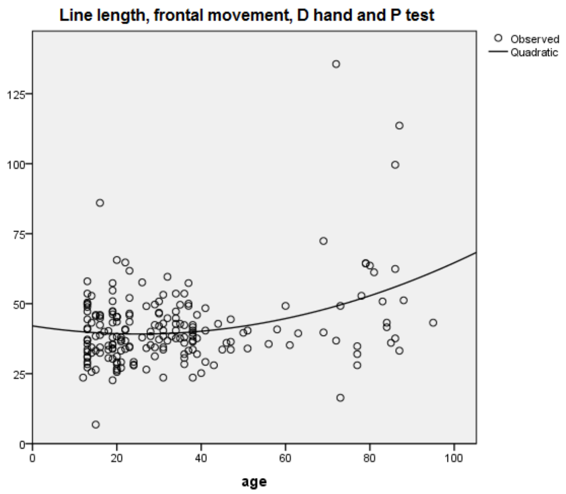
Tous, J.M., Muiños, R., and Liutsko, L. (2013). *Personality differences of applicants for the gun license (proprioceptive and verbal tests).* Manuscript submitted for publication.

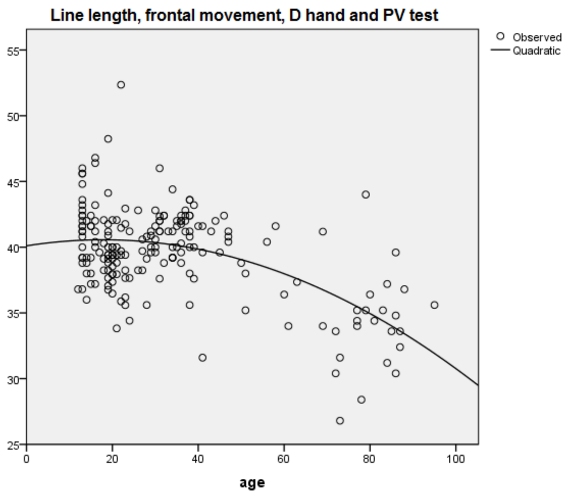
ANNEX 5. Modeling proprioceptive outcomes as a function of age using quadratic regression

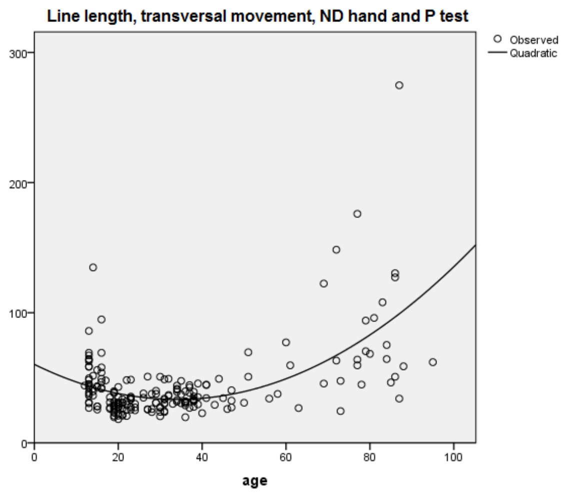
Scatterplots depicting quadratic regression lines for fine motor precision, absolute line length error, mm as a function of age in years

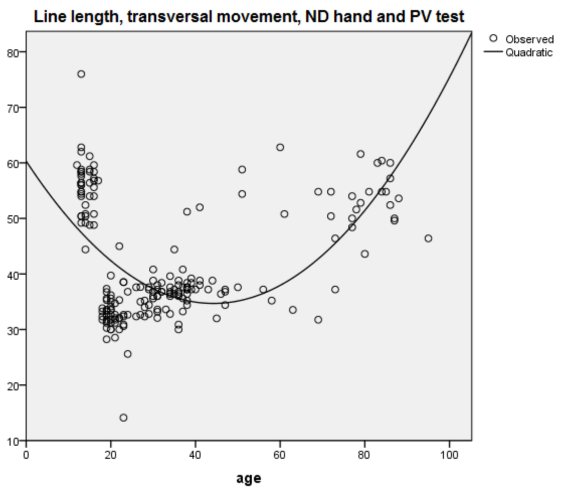
5.1. Line length

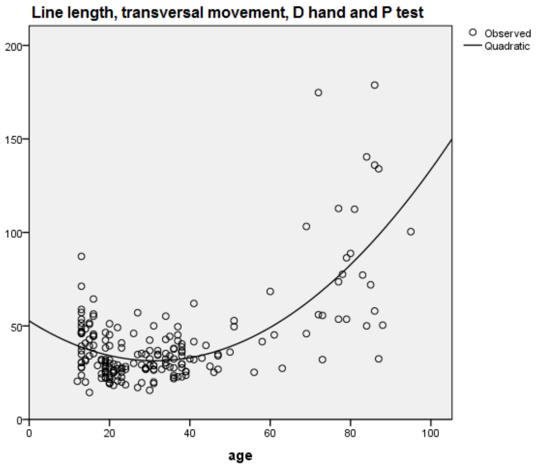


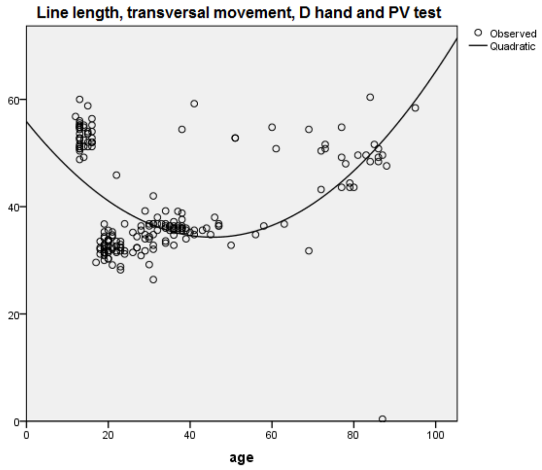


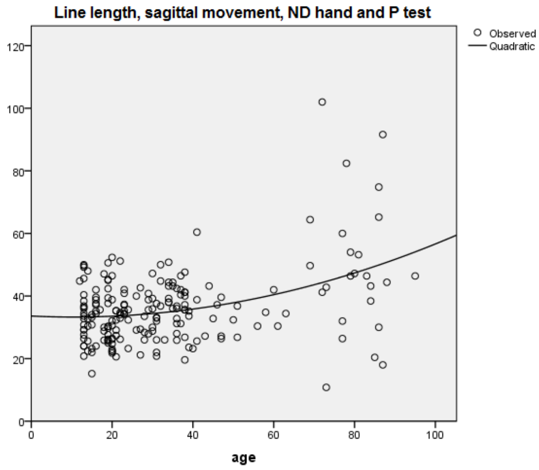




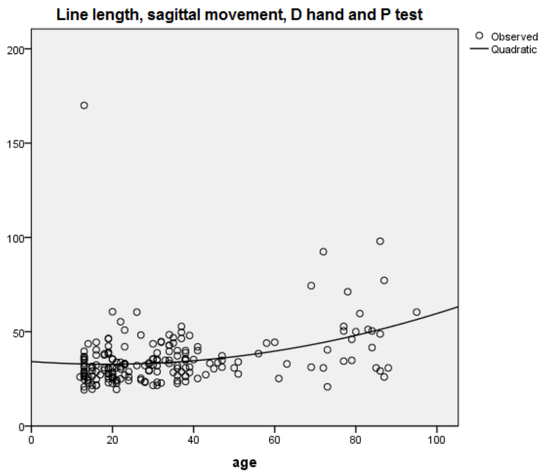


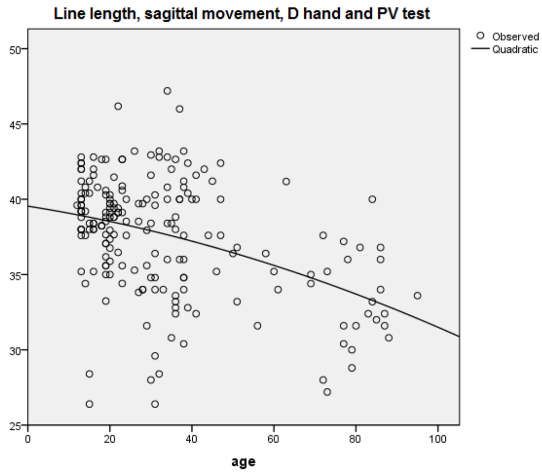

Line length, transversal movement, D hand and P test
Observed
Quadratic
age


Line length, transversal movement, D hand and PV test
Observed
Quadratic
age

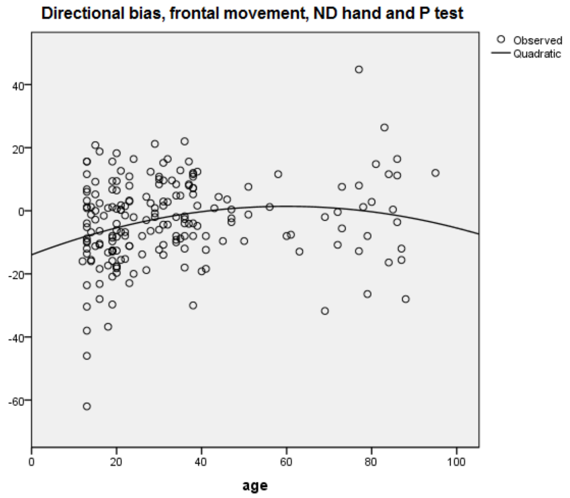

Line length, sagittal movement, ND hand and P test
Observed
Quadratic
age

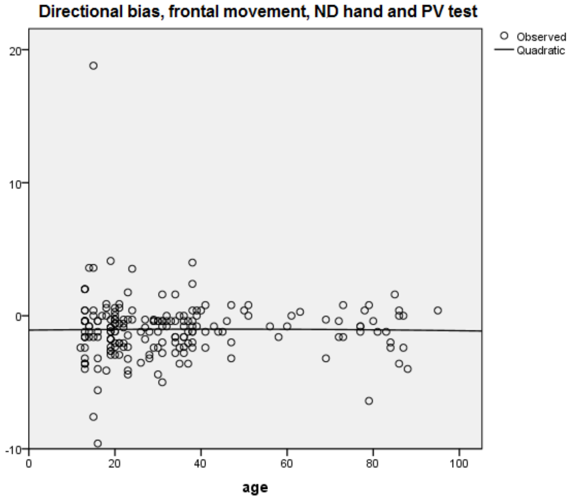

Line length, sagittal movement, ND hand and PV test
Observed
Quadratic
age

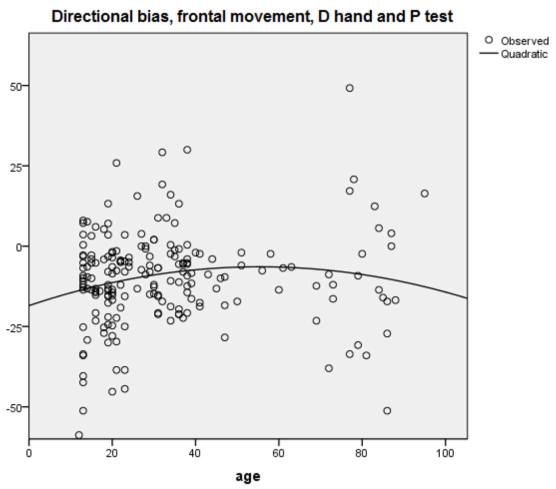

Line length, sagittal movement, D hand and P test
Observed
Quadratic
age

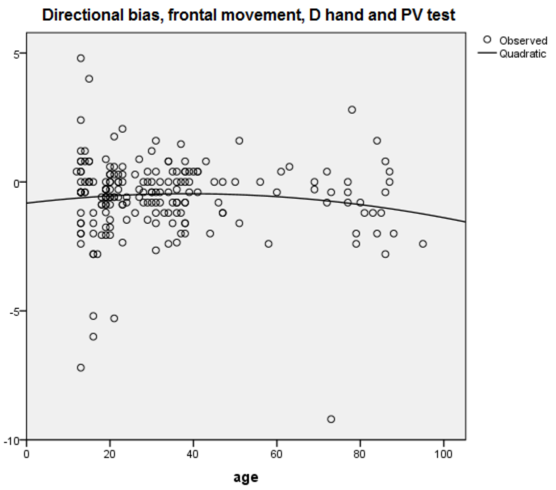

Line length, sagittal movement, D hand and PV test
Observed
Quadratic
age

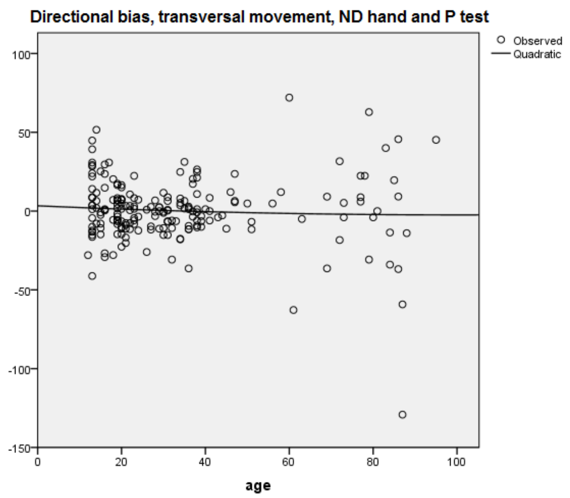
5.2. Directional bias

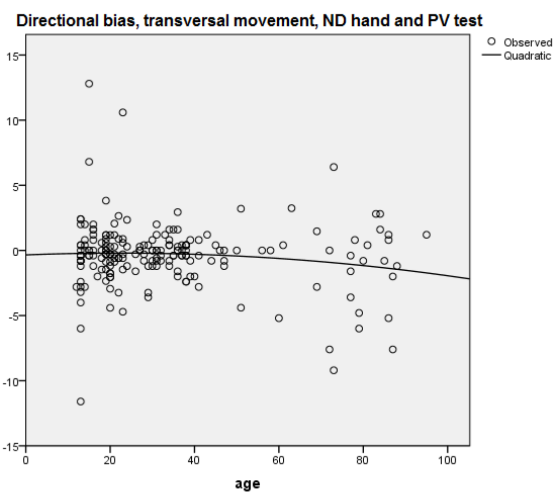


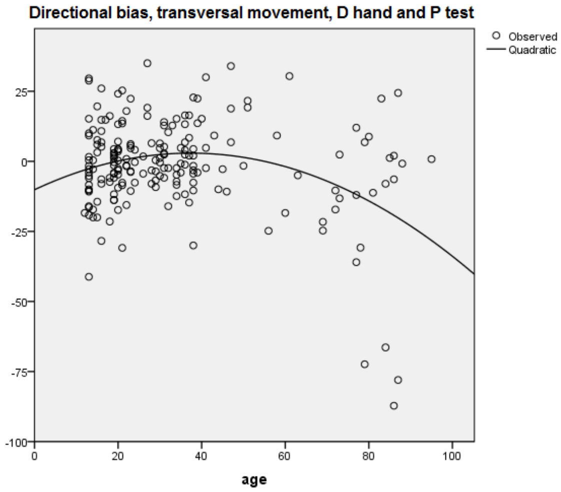


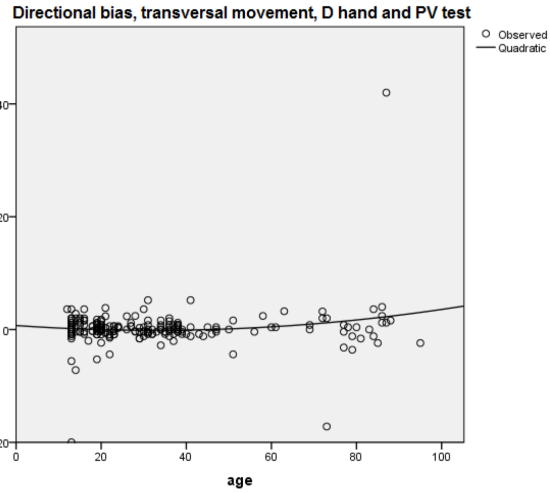


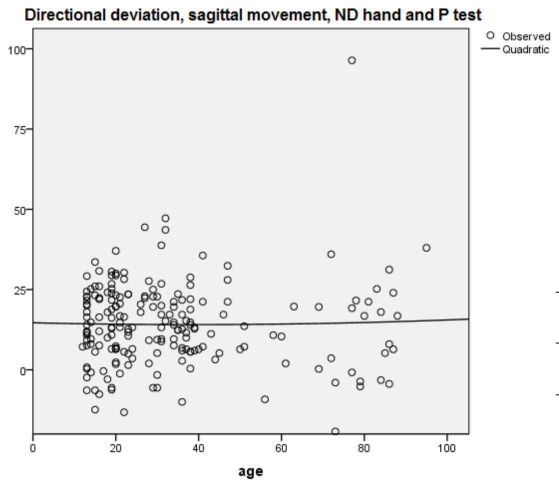


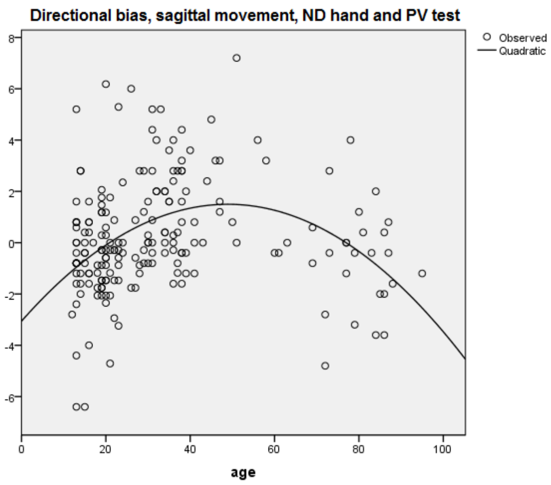


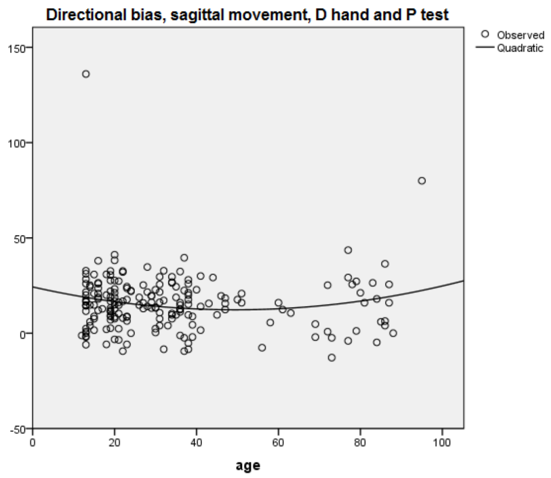


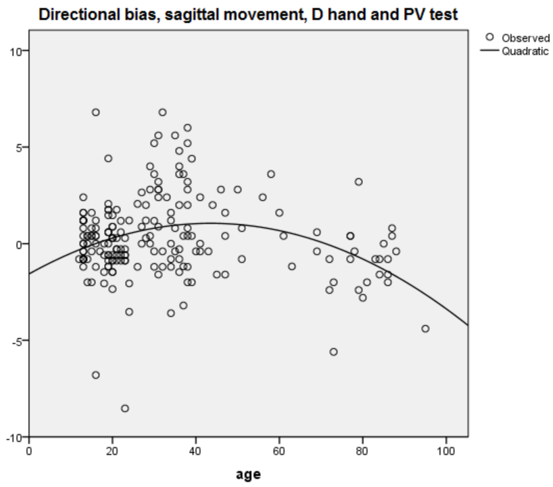

Directional bias, transversal movement, D hand and P test
Observed
Quadratic
age


Directional bias, transversal movement, D hand and PV test
Observed
Quadratic
age

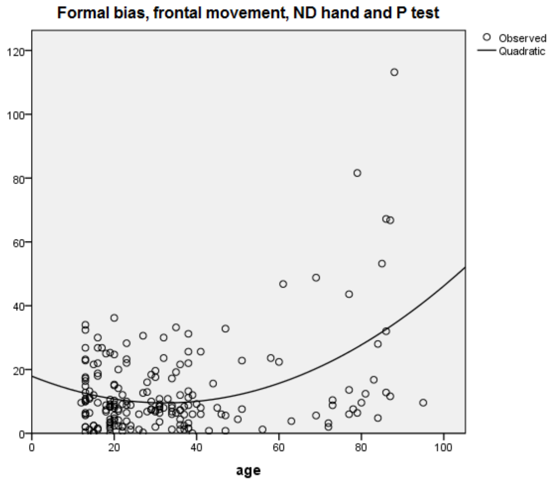

Directional deviation, sagittal movement, ND hand and P test
Observed
Quadratic
age

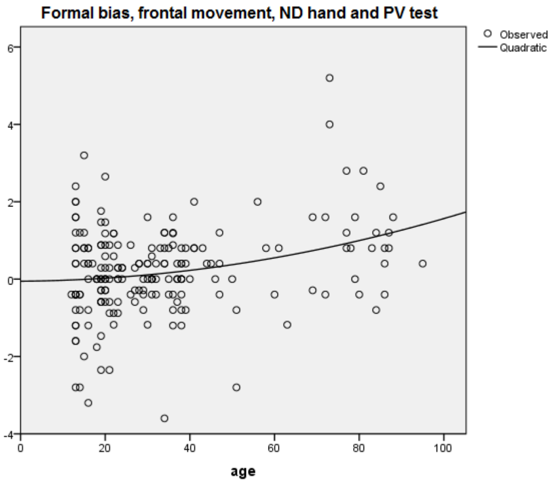

Directional bias, sagittal movement, ND hand and PV test
Observed
Quadratic
age

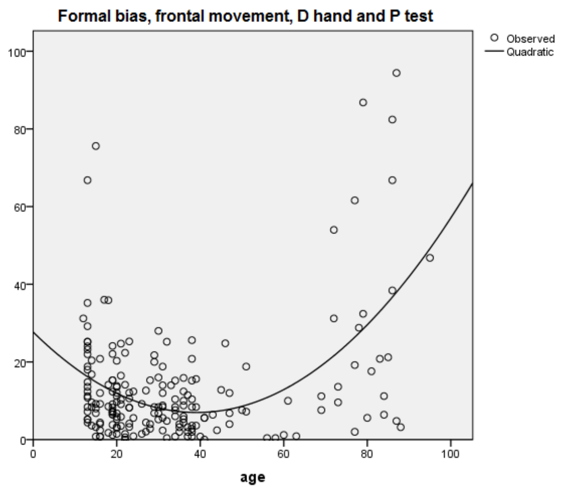

Directional bias, sagittal movement, D hand and P test
Observed
Quadratic
age

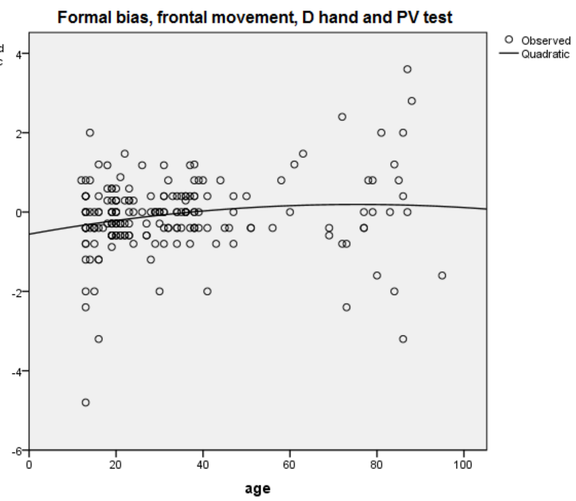

Directional bias, sagittal movement, D hand and PV test
Observed
Quadratic
age

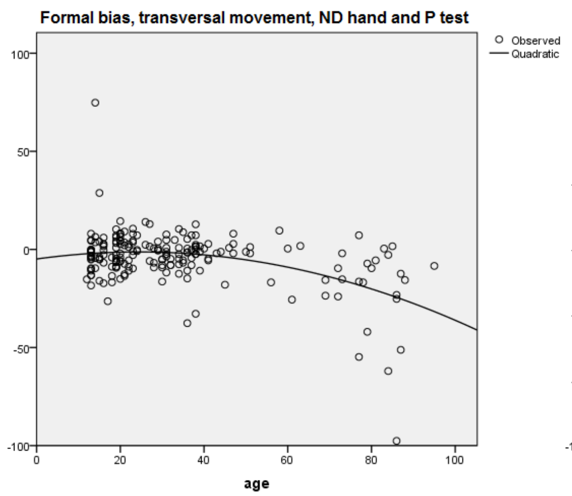
5.3. Formal bias

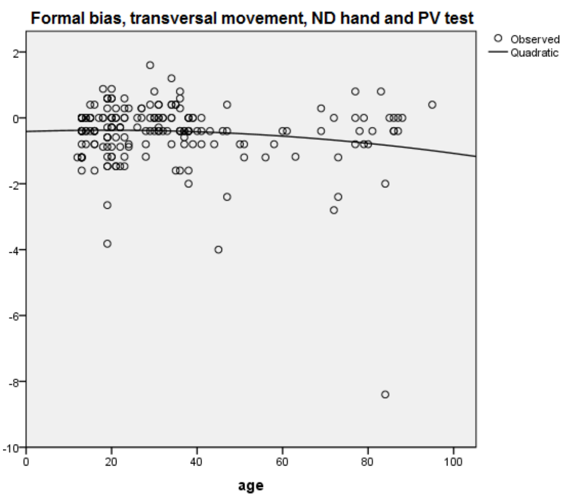


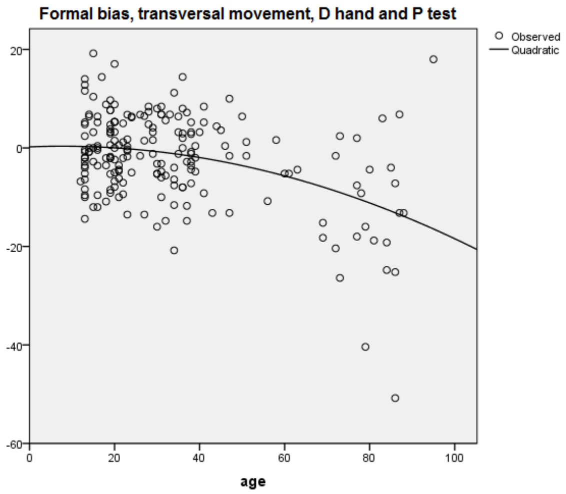


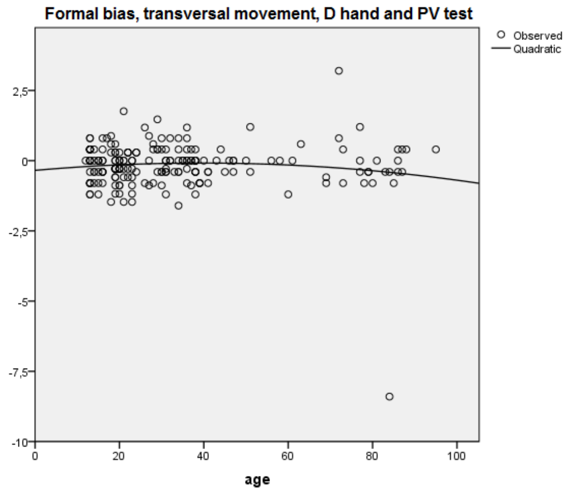


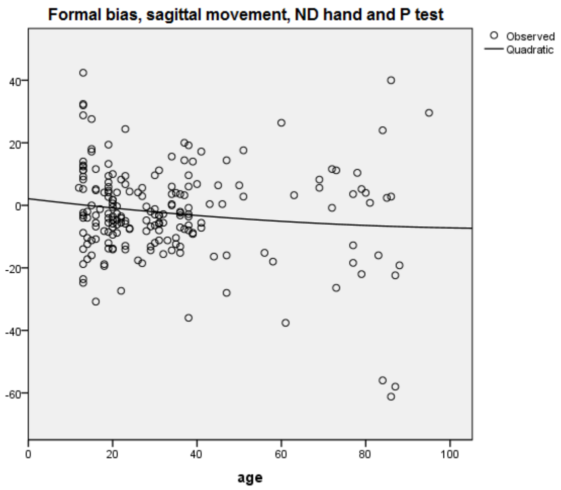


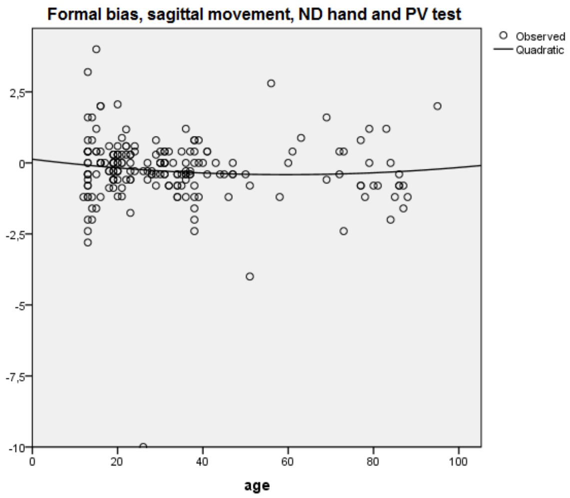


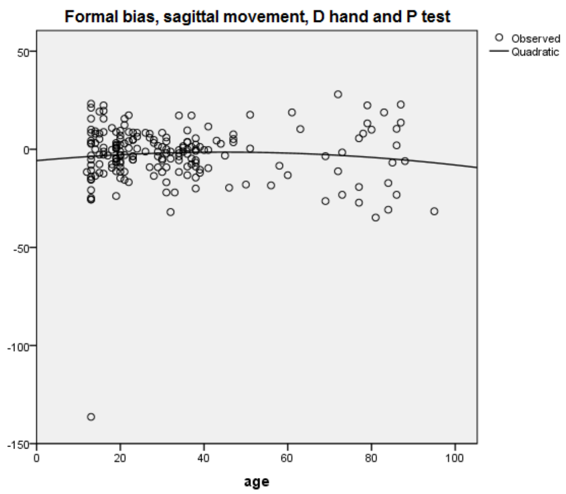


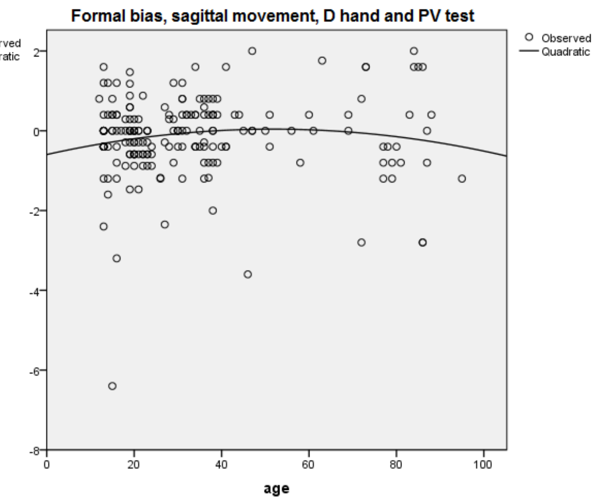

Formal bias, transversal movement, D hand and P test
Observed
Quadratic
age


Formal bias, transversal movement, D hand and PV test
Observed
Quadratic
age

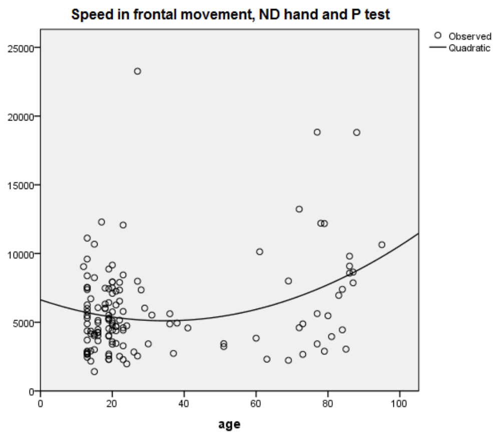

Formal bias, sagittal movement, ND hand and P test
Observed
Quadratic
age

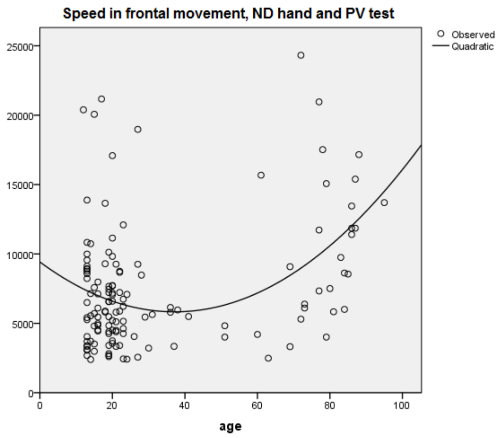

Formal bias, sagittal movement, ND hand and PV test
Observed
Quadratic
age

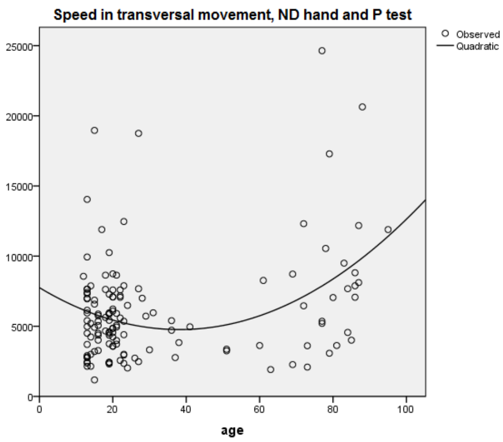

Formal bias, sagittal movement, D hand and P test
Observed
Quadratic
age

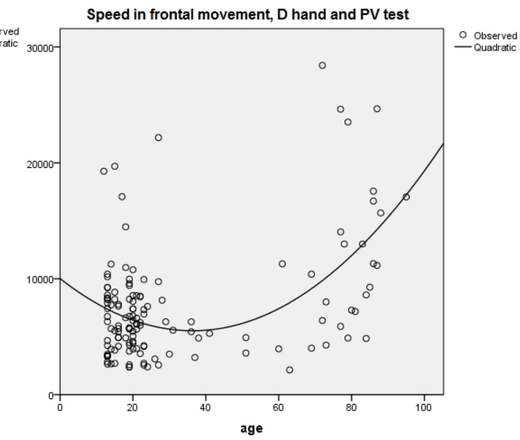

Formal bias, sagittal movement, D hand and PV test
Observed
Quadratic
age

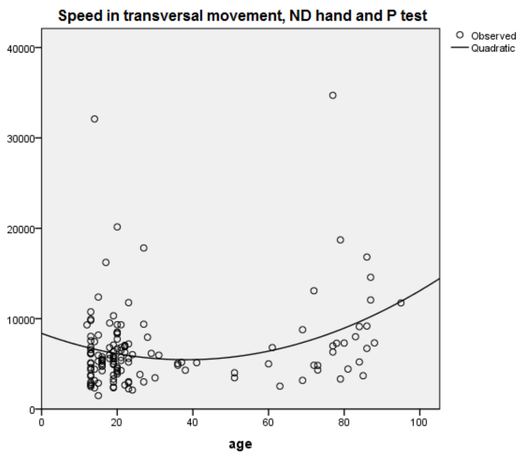
5.4. Speed

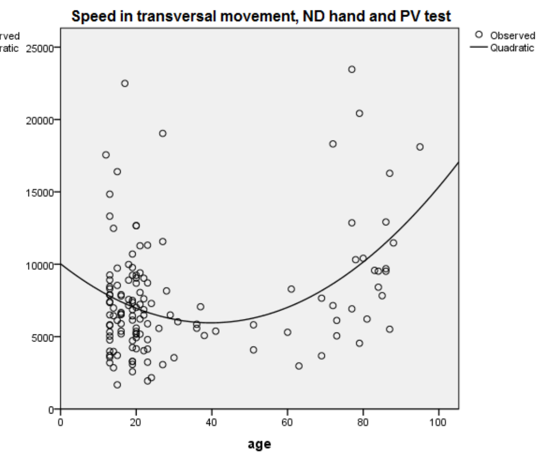

Speed in frontal movement, ND hand and P test
Observed
Quadratic
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
age

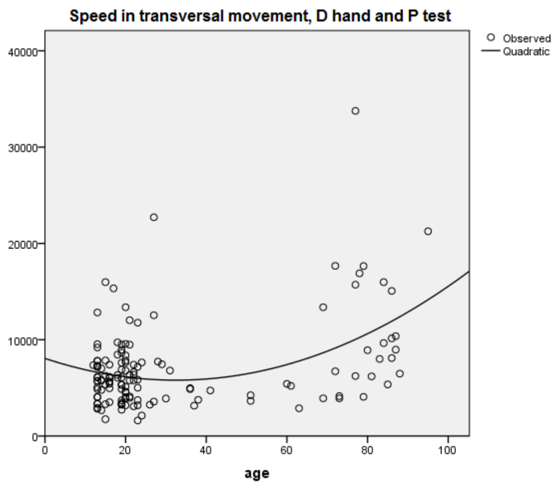

Speed in frontal movement, ND hand and PV test
Observed
Quadratic
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
age

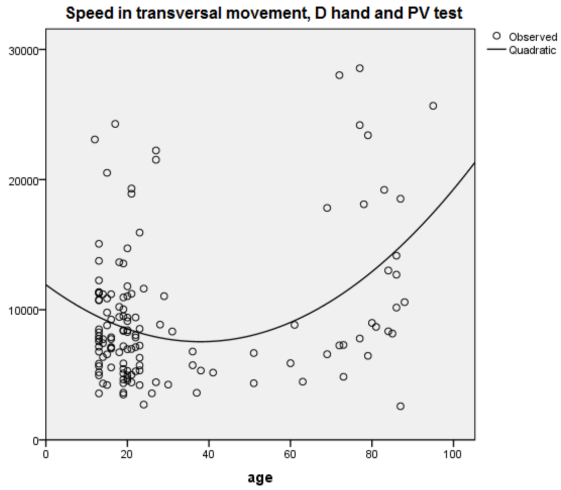

Speed in transversal movement, ND hand and P test
Observed
Quadratic
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
age

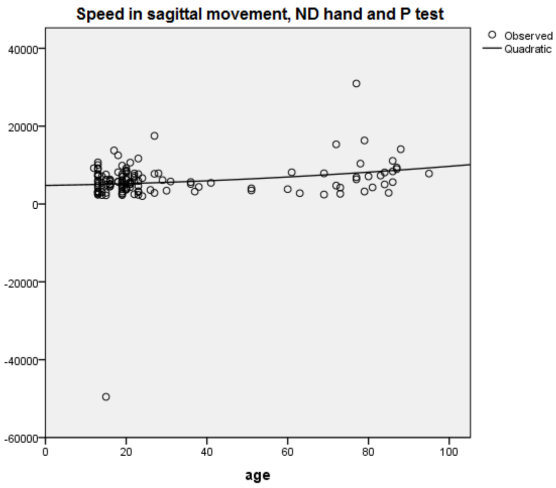

Speed in frontal movement, D hand and PV test
Observed
Quadratic
30000
20000
10000
0
0
20
40
60
80
100
age

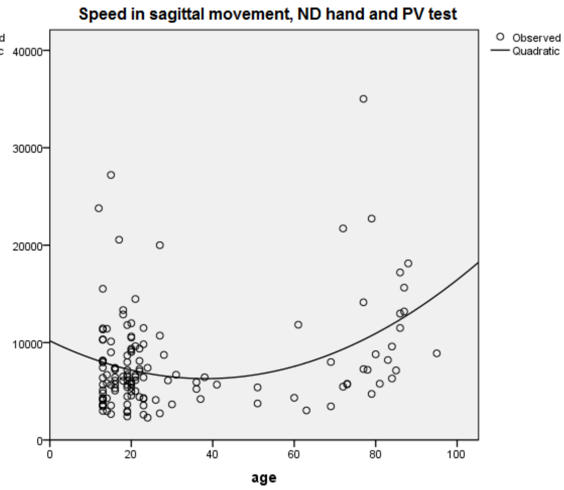

Speed in transversal movement, ND hand and P test
Observed
Quadratic
40000
30000
20000
10000
0
0
20
40
60
80
100
age

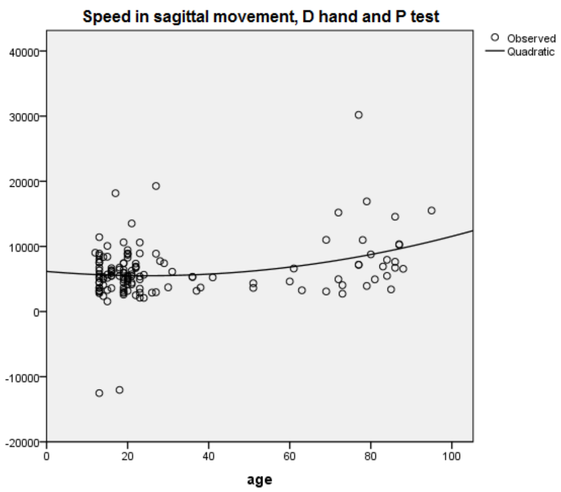

Speed in transversal movement, ND hand and PV test
Observed
Quadratic
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
age

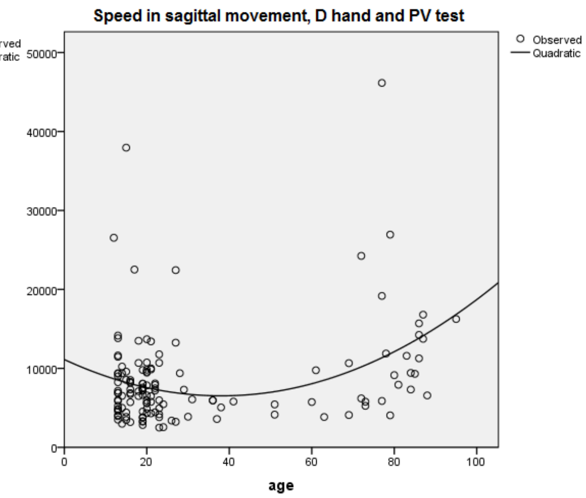

Speed in transversal movement, D hand and P test
Observed
Quadratic
age


Speed in transversal movement, D hand and PV test
Observed
Quadratic
age


Speed in sagittal movement, ND hand and P test
Observed
Quadratic
age


Speed in sagittal movement, ND hand and PV test
Observed
Quadratic
age

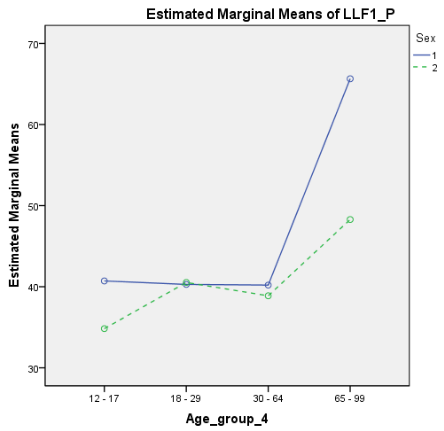

Speed in sagittal movement, D hand and P test
Observed
Quadratic
age

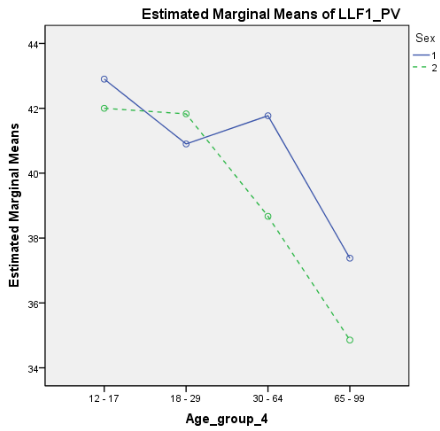

Speed in sagittal movement, D hand and PV test
Observed
Quadratic
age

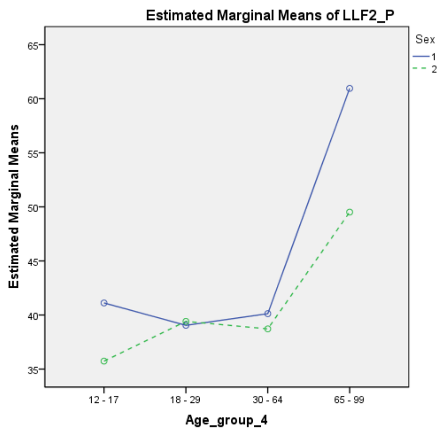
ANNEX 6. Age and sex-dependent differences in fine motor precision

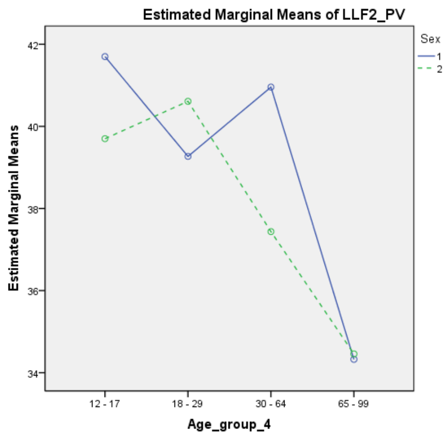
1) LL – line length (Y–axis - LL in mm, X–axis - four age groups)

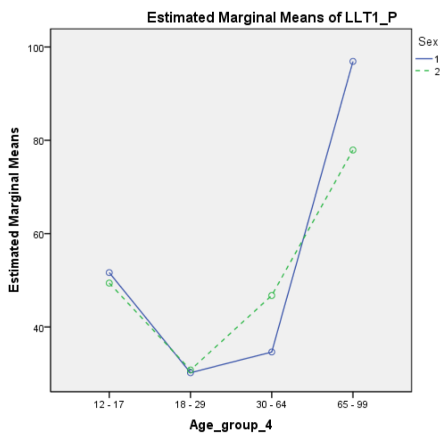
NOTE: Sex: 1 – Male, 2 – Female, LL – line length, movement type: F – frontal, T – transversal, S – sagittal with an index 1 – for non-dominant hand and 2 - for dominat hand; P – proprioceptive-only, PV – visuo-proprioceptive (sensory condition).

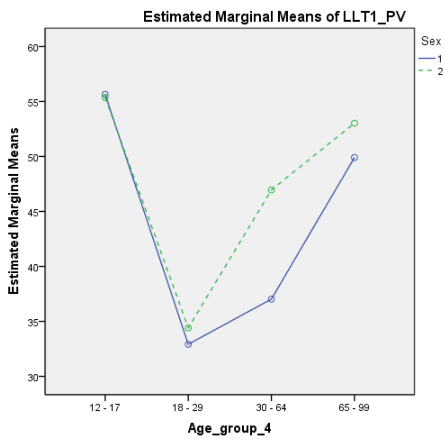


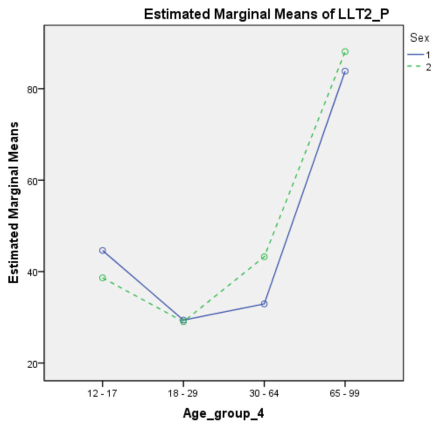


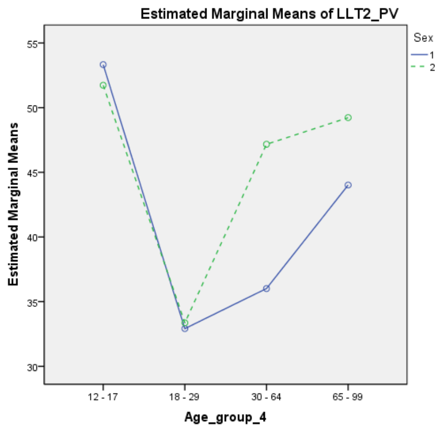


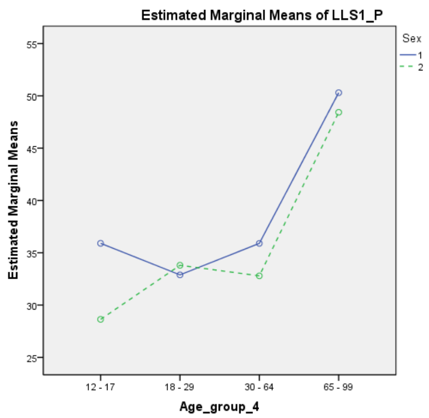


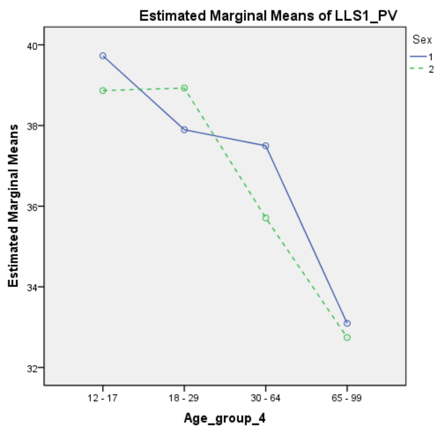


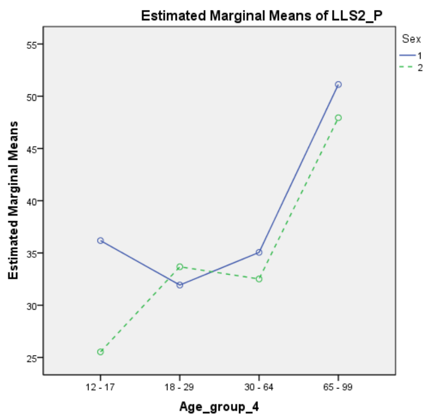


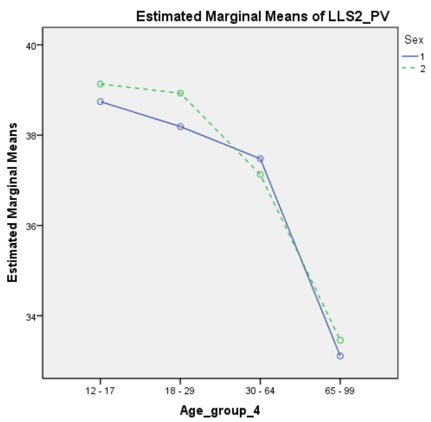






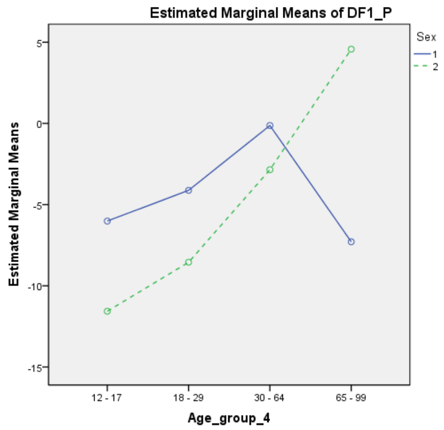


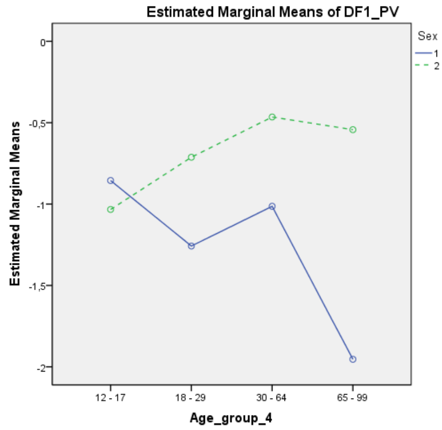


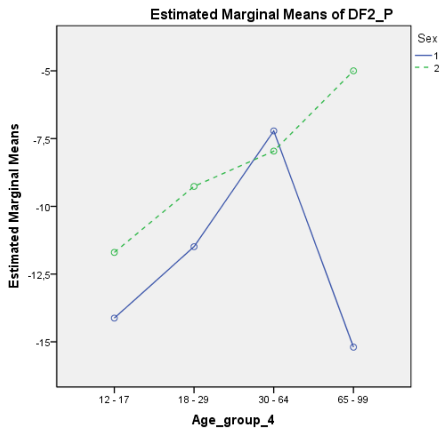


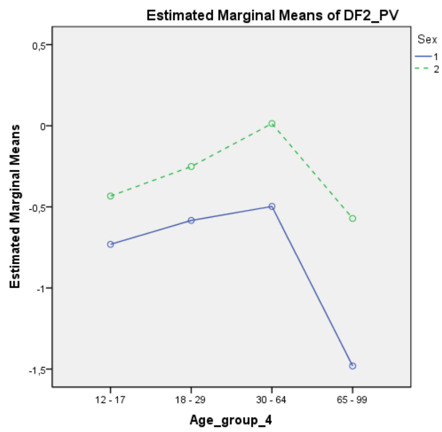
2) D – directional bias (Y–axis - deviation in mm, X–axis - four age groups)

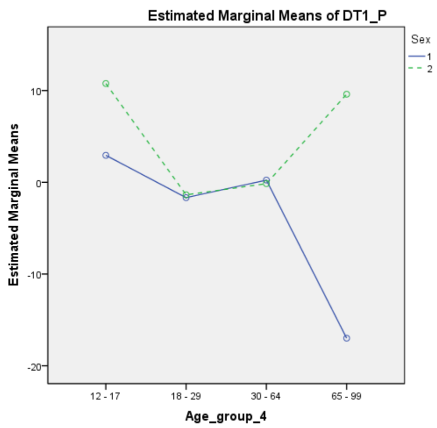
NOTE: Sex: 1 – Male, 2 – Female, D – directional bias, movement type: F – frontal, T – transversal, S – sagittal with an index 1 – for non-dominant hand and 2 - for dominat hand; P – proprioceptive-only, PV – visuo-proprioceptive (sensory condition).

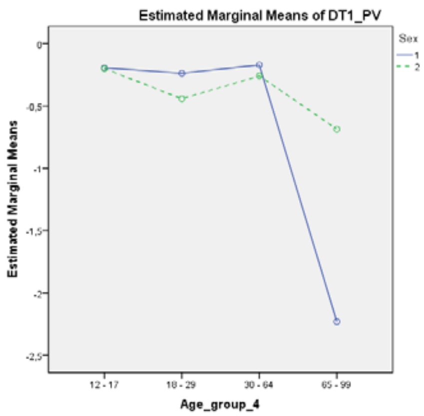

Estimated Marginal Means of DF1_P
Estimated Marginal Means
5
0
-5
-10
-15
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4
Sex
1
2

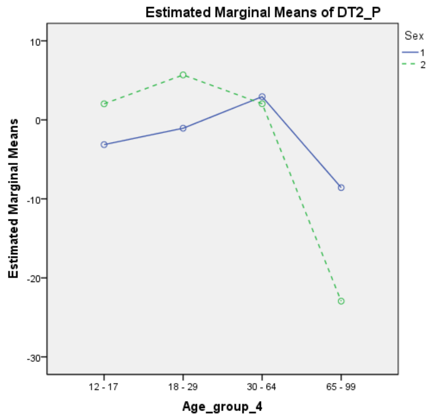

Estimated Marginal Means of DF1_PV
Estimated Marginal Means
0
-0,5
-1
-1,5
-2
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4
Sex
1
2

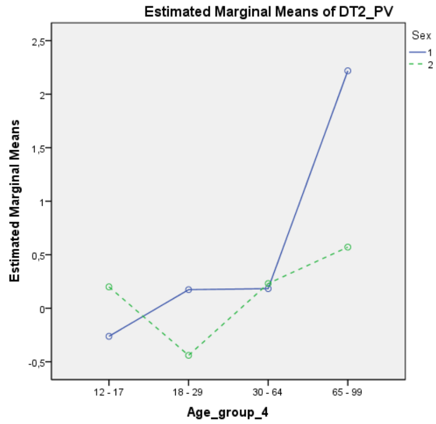

Estimated Marginal Means of DF2_P
Estimated Marginal Means
-5
-7,5
-10
-12,5
-15
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4
Sex
1
2

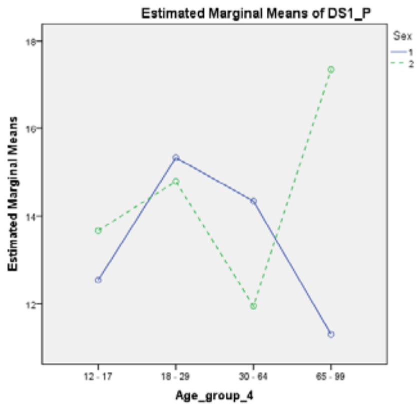

Estimated Marginal Means of DF2_PV
Estimated Marginal Means
0,5
0
-0,5
-1
-1,5
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4
Sex
1
2

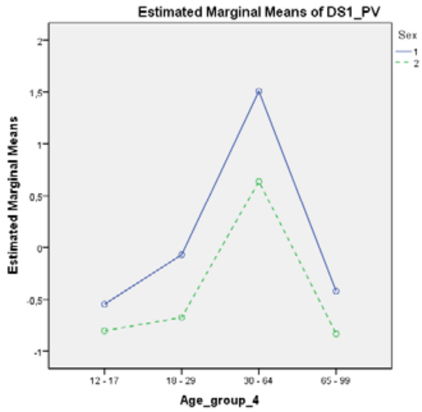

Estimated Marginal Means of DT1_P
Estimated Marginal Means
10
0
-10
-20
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4
Sex
1
2

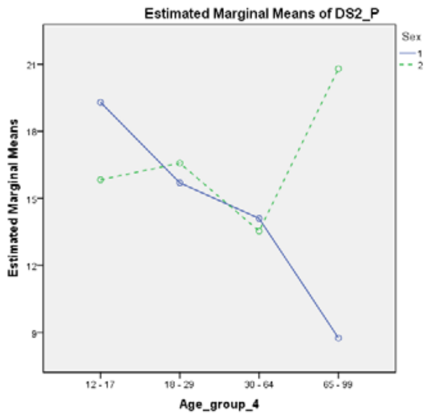

Estimated Marginal Means of DT1_PV
Estimated Marginal Means
0
-0,5
-1
-1,5
-2
-2,5
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4
Sex
1
2

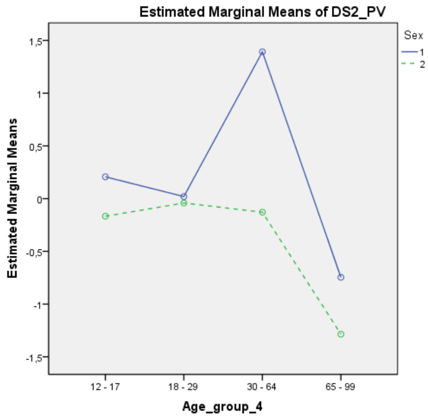






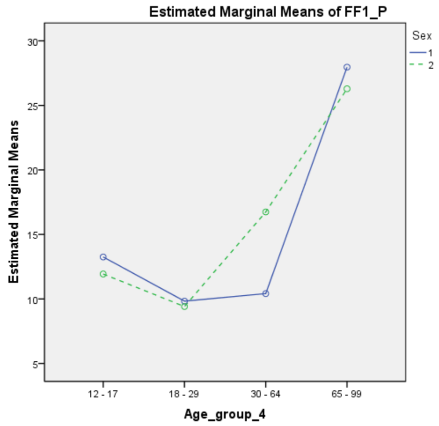


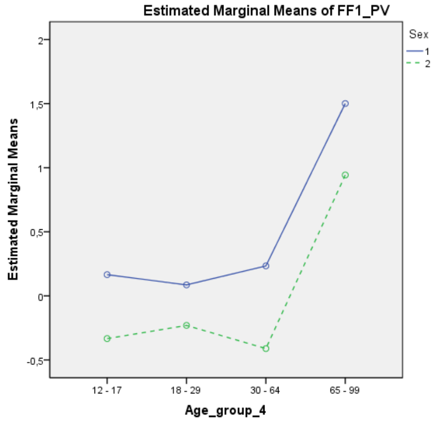


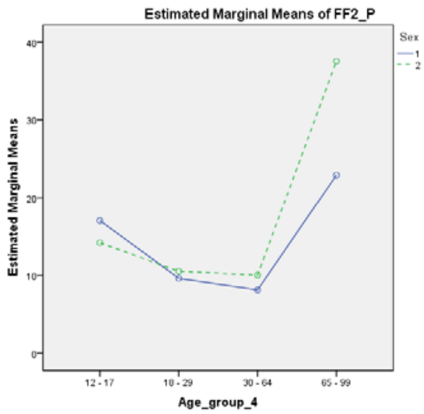


3) F – formal bias (Y–axis - deviation in mm, X–axis - four age groups)

NOTE: Sex: 1 – Male, 2 – Female, F– formal bias, movement type: F – frontal, T – transversal, S – sagittal with an index 1 – for non-dominant hand and 2 - for dominat hand; P – proprioceptive-only, PV – visuo-proprioceptive (sensory condition).


Estimated Marginal Means of FF1_P
Sex
1
2
Estimated Marginal Means
30
25
20
15
10
5
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4


Estimated Marginal Means of FF1_PV
Sex
1
2
Estimated Marginal Means
2
1,5
1
0,5
0
-0,5
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4


Estimated Marginal Means of FF2_P
Sex
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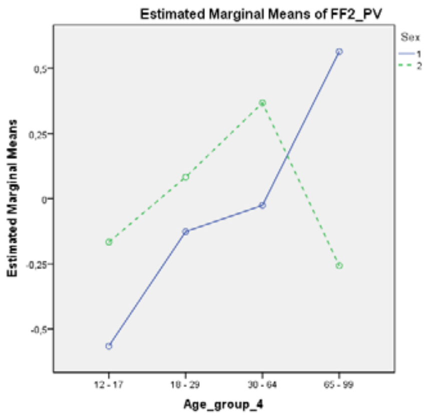
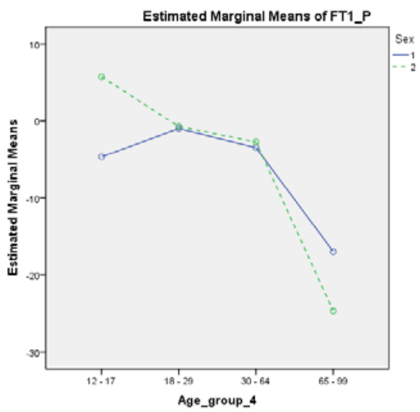
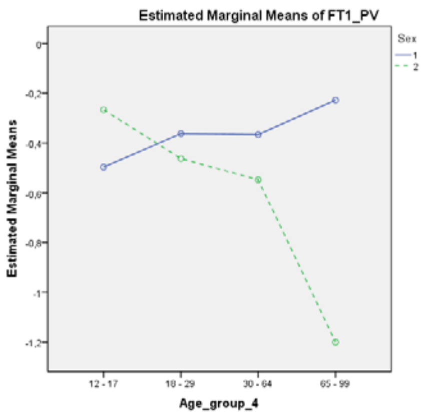
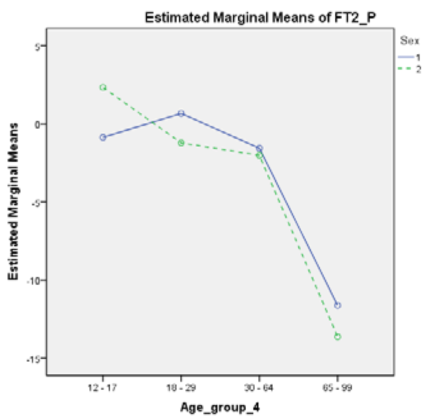
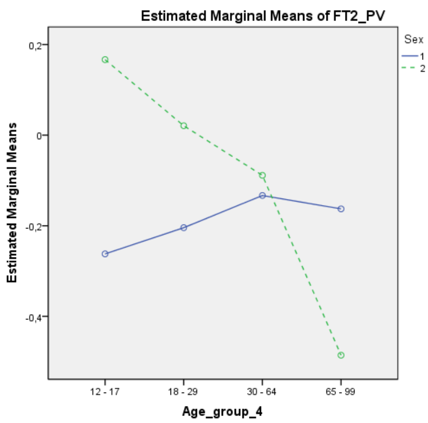
2
Estimated Marginal Means
40
30
20
10
0
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4

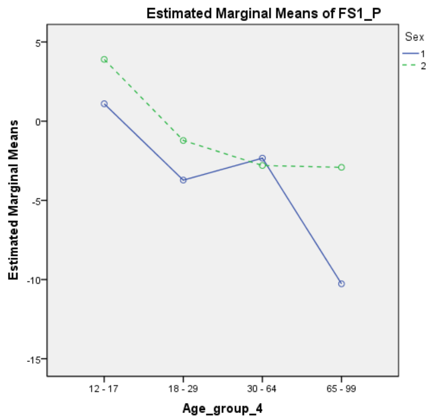

Estimated Marginal Means of FF2_PV
Sex
1
2
Estimated Marginal Means
0,5
0,25
0
-0,25
-0,5
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4

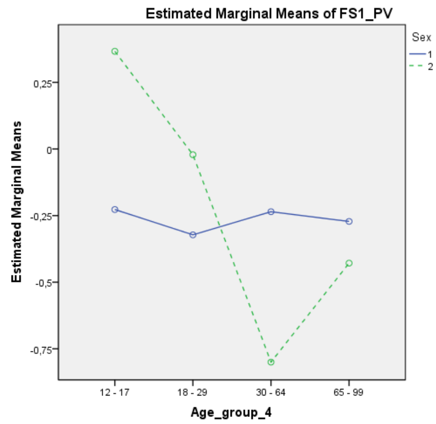

Estimated Marginal Means of FT1_P
Sex
1
2
Estimated Marginal Means
10
0
-10
-20
-30
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4

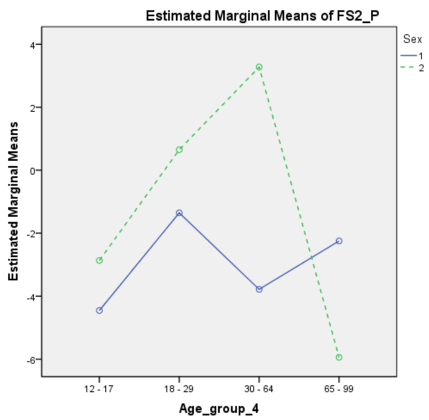

Estimated Marginal Means of FT1_PV
Sex
1
2
Estimated Marginal Means
0
-0,2
-0,4
-0,6
-0,8
-1
-1,2
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4

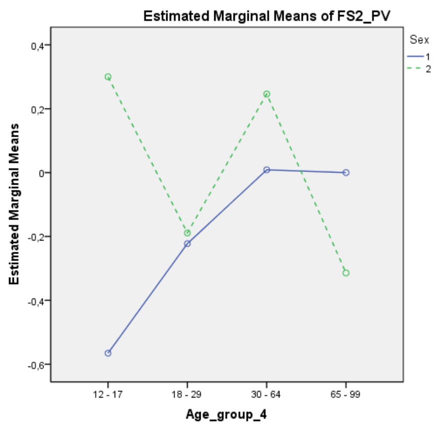

Estimated Marginal Means of FT2_P
Sex
1
2
Estimated Marginal Means
5
0
-5
-10
-15
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4


Estimated Marginal Means of FT2_PV
Sex
1
2
Estimated Marginal Means
0,2
0
-0,2
-0,4
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4



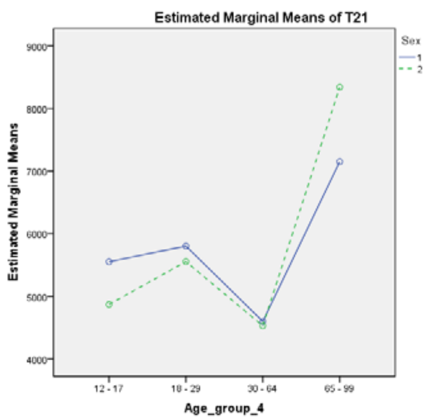


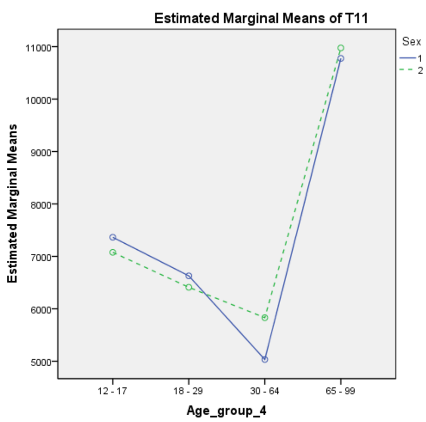


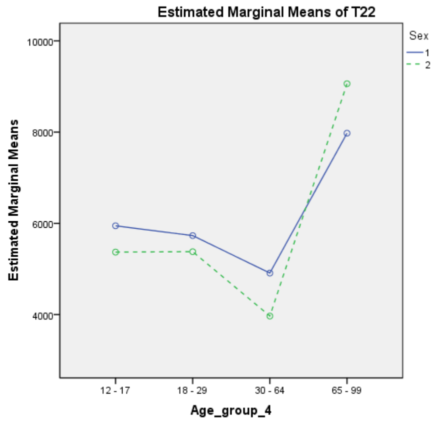


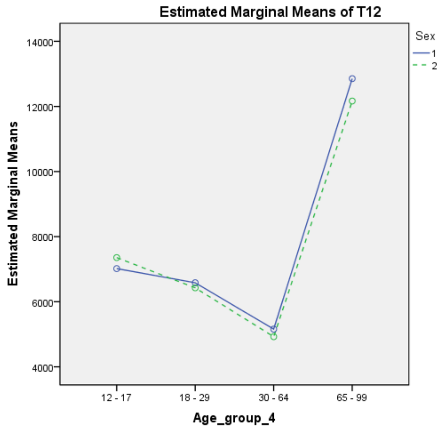
4) Speed (T) (Y–axis - velocity in msec, X–axis - four age groups)

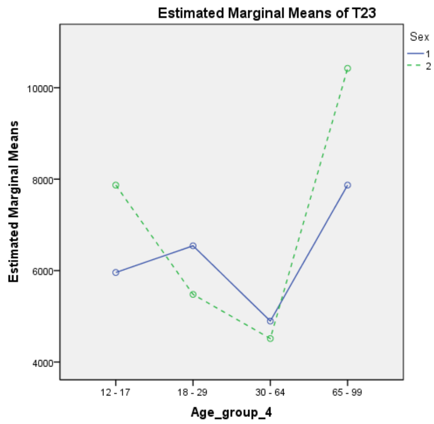
NOTE: Sex: 1 – Male, 2 – Female, F– formal bias; numerical indexes: a) first number stands for sensory condition: 1 – PV and 2; b) the second number stands for movement type and hand: 1 and 2 - frontal, 3 and 4 – transversal, 5 and 6 – sagittal with impair numbers for non-dominat hand and paired for dominant hand.

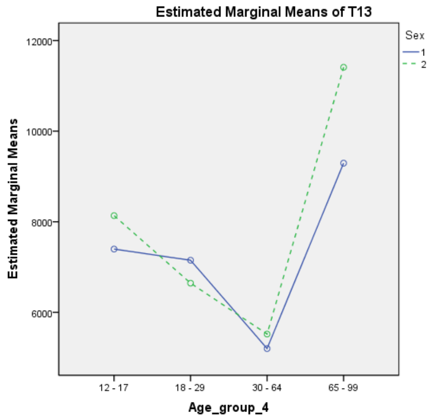


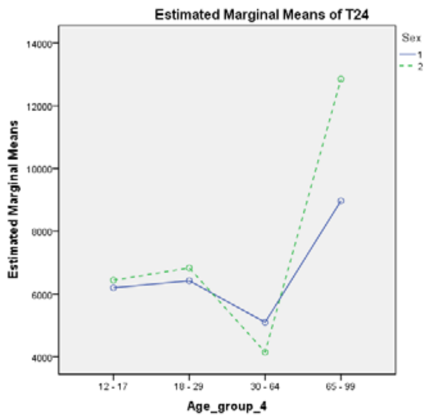


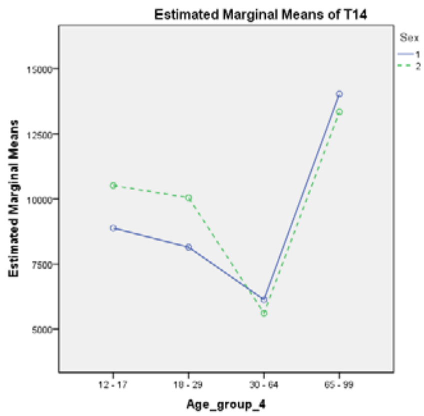

Estimated Marginal Means of T22
Estimated Marginal Means
Age_group_4
12 - 17
18 - 29
30 - 64
65 - 99
Sex
1
2

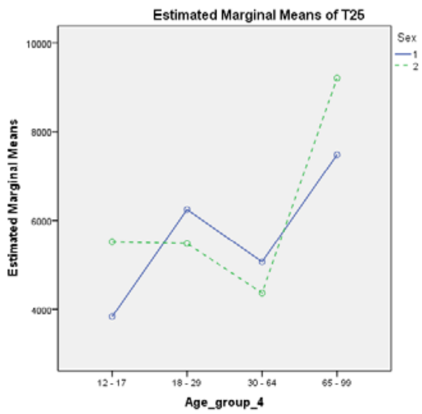

Estimated Marginal Means of T12
Estimated Marginal Means
Age_group_4
12 - 17
18 - 29
30 - 64
65 - 99
Sex
1
2

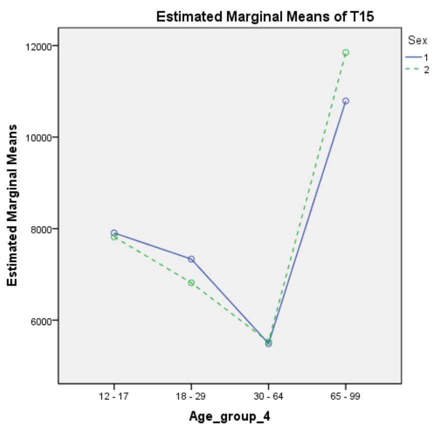

Estimated Marginal Means of T23
Estimated Marginal Means
Age_group_4
12 - 17
18 - 29
30 - 64
65 - 99
Sex
1
2

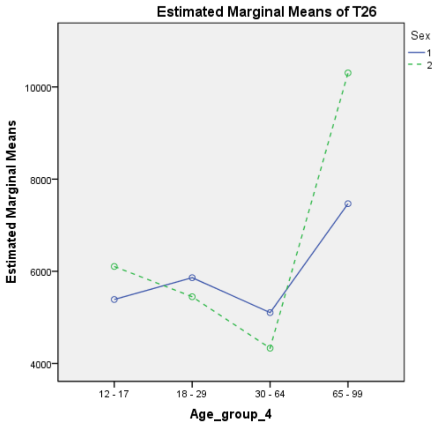

Estimated Marginal Means of T13
Estimated Marginal Means
Age_group_4
12 - 17
18 - 29
30 - 64
65 - 99
Sex
1
2

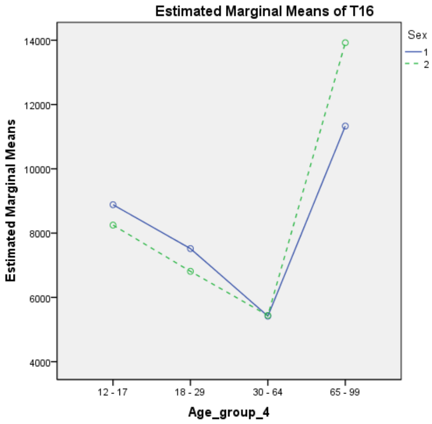

Estimated Marginal Means of T24
Estimated Marginal Means
Age_group_4
12 - 17
18 - 29
30 - 64
65 - 99
Sex
1
2


Estimated Marginal Means of T14
Estimated Marginal Means
Age_group_4
12 - 17
18 - 29
30 - 64
65 - 99
Sex
1
2


Estimated Marginal Means of T25
Estimated Marginal Means
Age_group_4
12 - 17
18 - 29
30 - 64
65 - 99
Sex
1
2


Estimated Marginal Means of T15
Estimated Marginal Means
Age_group_4
12 - 17
18 - 29
30 - 64
65 - 99
Sex
1
2


Estimated Marginal Means of T26
Sex
1
2
Estimated Marginal Means
10000
8000
6000
4000
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4


Estimated Marginal Means of T16
Sex
1
2
Estimated Marginal Means
14000
12000
10000
8000
6000
4000
12 - 17
18 - 29
30 - 64
65 - 99
Age_group_4

ANNEX 7. Supplemental tables

Table A1. Descriptive statistics for observable variables in both sex subgroups

			sex	Male				Female			
						CI 95%				CI 95%	
Bias	MT	Hand	SC	*M*	*SD*	Upper limit	Lower limit	*M*	*SD*	Upper limit	Lower limit
LL	Frontal	ND	PV	41.00	0.44	40.14	41.86	39.31	0.58	38.16	40.46
			P	43.83	1.82	40.22	47.44	41.09	2.43	36.29	45.89
		D	PV	39.33	0.42	38.51	40.15	38.06	0.55	36.96	39.15
			P	42.68	1.78	39.16	46.19	41.32	2.37	36.64	46.00
	Transvers	ND	PV	42.67	1.26	40.18	45.16	47.17	1.67	43.86	50.48
			P	45.97	3.65	38.74	53.20	51.84	4.86	42.23	61.46
		D	PV	41.16	1.16	38.86	43.46	44.88	1.55	41.82	47.95
			P	41.68	3.15	35.45	47.92	51.03	4.19	42.74	59.33
	Sagittal	ND	PV	37.89	0.42	37.05	38.73	36.57	0.57	35.45	37.69
			P	35.95	1.47	33.04	38.87	36.61	1.96	32.73	40.49
		D	PV	37.87	0.39	37.09	38.65	37.08	0.53	36.05	38.12
			P	35.78	1.93	31.97	39.60	35.61	2.57	30.53	40.68
D	Frontal	ND	PV	-1.52	0.22	-1.94	-1.09	-0.70	0.29	-1.27	-0.13
			P	-5.89	1.58	-9.01	-2.77	-4.53	2.10	-8.68	-0.38
		D	PV	-0.77	0.19	-1.15	-0.40	-0.35	0.25	-0.84	0.15
			P	-14.03	1.68	-17.35	-10.71	-8.41	2.23	-12.83	-4.00
	Transvers	ND	PV	-0.40	0.33	-1.05	0.24	-0.42	0.43	-1.28	0.43
			P	-1.92	2.55	-6.96	3.12	5.07	3.39	-1.64	11.78
		D	PV	0.34	0.51	-0.67	1.35	0.13	0.68	-1.22	1.47
			P	-2.20	2.12	-6.40	1.99	-4.18	2.82	-9.76	1.40
	Sagittal	ND	PV	-0.39	0.22	-0.82	0.05	-0.39	0.22	-0.82	0.05
			P	14.00	1.51	11.02	16.98	14.78	2.00	10.81	18.74
		D	PV	-0.11	0.19	-0.49	0.27	-0.45	0.25	-0.95	0.05
			P	15.76	1.82	12.16	19.36	17.12	2.42	12.32	21.91
F	Frontal	ND	PV	0.34	0.14	0.06	0.61	0.06	0.19	-0.32	0.43
			P	13.36	1.77	9.85	16.86	16.19	2.36	11.53	20.85
		D	PV	-0.17	0.12	-0.40	0.06	-0.03	0.16	-0.34	0.28
			P	13.88	1.90	10.12	17.64	19.25	2.53	14.25	24.26
	Transvers	ND	PV	-0.40	0.11	-0.62	-0.18	-0.64	0.15	-0.93	-0.35
			P	-4.54	1.76	-8.02	-1.06	-6.41	2.34	-11.04	-1.78
		D	PV	-0.24	0.11	-0.45	-0.02	-0.11	0.15	-0.40	0.18
			P	-1.72	1.11	-3.91	0.48	-4.08	1.48	-7.01	-1.16
	Sagittal	ND	PV	-0.17	0.12	-0.40	0.07	-0.17	0.16	-0.48	0.13
			P	-2.56	1.81	-6.15	1.03	-0.70	2.41	-5.47	4.08
		D	PV	-0.32	0.12	-0.54	-0.09	-0.03	0.15	-0.33	0.27
			P	-2.19	1.88	-5.91	1.54	-1.71	2.51	-6.67	3.24
T	Frontal	ND	PV	7.330	490	6.361	8.299	7.812	652	6.523	9.101
			P	5.806	367	5.080	6.533	6.025	489	5.058	6.991
		D	PV	7.449	541	6.378	8.520	8.084	720	6.659	9.508
			P	6.043	413	5.227	6.859	6.215	549	5.129	7.301
	Transvers	ND	PV	7.404	444	6.525	8.282	8.220	591	7.051	9.389
			P	6.418	513	5.403	7.434	7.358	683	6.007	8.709
		D	PV	9.044	599	7.860	10.229	10.386	797	8.810	11.962

		P	6.598	490	5.628	7.568	8.042	652	6.751	9.332
Sagittal	ND	PV	7.870	562	6.757	8.982	8.320	748	6.839	9.800
		P	5.510	660	4.206	6.815	6.390	878	4.654	8.127
	D	PV	8.354	681	7.008	9.700	9.016	906	7.224	10.807
		P	5.823	482	4.870	6.777	6.843	641	5.574	8.112

Legend: Bias types: LL – line length, D – directional (bias), F formal (bias), T – speed, MT – movement type; SC – sensory conditions: PV – proprioceptive-visual, P – proprioceptive-only; ND – non-dominant (hand) and D – dominant (hand).

Table A2. Descriptive statistics for dominant and non-dominant hands in LL (mm)

MT	SC	Hand	*M*	*SD*
Frontal	PV	ND	40.39	4.09
		D	38.90	3.87
		Total	39.64	4.04
	P	ND	42.85	16.73
		D	42.21	16.28
		Total	42.53	16.48
	Total	ND	41.63	12.24
		D	40.55	11.93
		Total	41.09	12.08
Transversal	PV	ND	44.42	11.80
		D	42.57	10.82
		Total	43.50	11.34
	P	ND	48.06	33.54
		D	45.02	29.19
		Total	46.54	31.42
	Total	ND	46.24	25.16
		D	43.79	22.01
		Total	45.02	23.65
Sagittal	PV	ND	37.43	3.94
		D	37.61	3.64
		Total	37.52	3.79
	P	ND	36.17	13.49
		D	35.67	17.65
		Total	35.92	15.68
	Total	ND	36.80	9.94
		D	36.64	12.76
		Total	36.72	11.43
Total	PV	ND	40.75	8.08
		D	39.69	7.25
		Total	40.22	7.69
	P	ND	42.36	23.46
		D	40.97	22.12
		Total	41.66	22.79
	Total	ND	41.56	17.56
		D	40.33	16.46
		Total	40.94	17.02

Table A3. Descriptive statisctics for dominant and non-dominant hands in D bias

MT	SC	Hand	Mean	SD
Frontal	PV	ND	-1.22	2.02
		D	-0.61	1.75
		Total	-0.91	1.91
	P	ND	-5.38	14.45
		D	-11.89	15.64
		Total	-8.63	15.38
	Total	ND	-3.31	10.52
		D	-6.25	12.46
		Total	-4.78	11.62
Transversal	PV	ND	-0.41	2.98
		D	0.27	4.67
		Total	-0.07	3.93
	P	ND	0.54	23.58
		D	-2.87	19.43
		Total	-1.17	21.63
	Total	ND	0.06	16.78
		D	-1.30	14.19
		Total	-0.62	15.54
Sagittal	PV	ND	-0.43	2.01
		D	-0.24	1.76
		Total	-0.33	1.89
	P	ND	14.22	13.81
		D	16.24	16.68
		Total	15.23	15.32
	Total	ND	6.89	12.28
		D	8.00	14.43
		Total	7.45	13.40
Total	PV	ND	-0.69	2.41
		D	-0.19	3.07
		Total	-0.44	2.77
	P	ND	3.12	19.61
		D	0.49	20.89
		Total	1.81	20.29
	Total	ND	1.22	14.10
		D	0.15	14.93
		Total	0.69	14.52

Table A4. Descriptive statisctics for dominant and non-dominant hands in F bias

MT	SC	Hand	*M*	*SD*
Frontal	PV	ND	0.23	1.30
		D	-0.12	1.08
		Total	0.05	1.21
	P	ND	14.29	16.29
		D	15.71	17.63
		Total	15.00	16.96

	Total	ND	7.29	13.53
		D	7.79	14.78
		Total	7.54	14.16
Transversal	PV	ND	-0.49	1.02
		D	-0.19	1.00
		Total	-0.34	1.02
	P	ND	-5.30	16.14
		D	-2.55	10.23
		Total	-3.92	13.56
	Total	ND	-2.89	11.67
		D	-1.37	7.35
		Total	-2.13	9.77
Sagittal	PV	ND	-0.17	1.07
		D	-0.21	1.06
		Total	-0.19	1.06
	P	ND	-1.74	16.70
		D	-2.09	17.26
		Total	-1.91	16.95
	Total	ND	-0.95	11.84
		D	-1.15	12.24
		Total	-1.05	12.03
Total	PV	ND	-0.14	1.17
		D	-0.17	1.04
		Total	-0.16	1.11
	P	ND	2.42	18.43
		D	3.69	17.58
		Total	3.05	18.01
	Total	ND	1.14	13.12
		D	1.76	12.59
		Total	1.45	12.86

Table A5. Descriptive statisctics for dominant and non-dominant hands in Speed.

MT	SC	Hand	*M*	*SD*
Frontal	PV	ND	7504	4503
		D	7687	4963
		Total	7596	4731
	P	ND	5903	3367
		D	6111	3776
		Total	6007	3572
	Total	ND	6700	4046
		D	6899	4471
		Total	6800	4262
Transversal	PV	ND	7704	4083
		D	9530	5516
		Total	8617	4929
	P	ND	6768	4720
		D	7124	4539
		Total	6946	4625

	Total	ND	7236	4430
		D	8327	5184
		Total	7782	4848
Sagittal	PV	ND	8039	5151
		D	8600	6236
		Total	8320	5716
	P	ND	5841	6051
		D	6220	4450
		Total	6031	5305
	Total	ND	6940	5716
		D	7410	5537
		Total	7175	5627
Total	PV	ND	7750	4594
		D	8606	5633
		Total	8178	5155
	P	ND	6171	4845
		D	6485	4282
		Total	6328	4572
	Total	ND	6959	4784
		D	7545	5112
		Total	7253	4958