Original article (short paper)

Intermanual Transfer of Learning in a Fine Manual Skill Task

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Abstract — Intermanual Transfer of Learning (IMTL) is the ability to learn a certain skill in an easier way with one hand after that skill has been learnt by the opposite hand[1]. This research aimed to investigate IMTL in a Fine Manual Dexterity (FMD) task in subjects presenting different Hand Preference (HP). The sample comprised 882 right and left-handers, both genders, aged 6 to 95 years old. The Dutch Handedness Questionnaire[2] was used to assess HP and the Purdue Pegboard Test[3] evaluated FMD. Direction and intensity of HP, Direction of Transfer (DT), gender, age and nationality were analyzed. IMTL changed according to DT and age, tending to be asymmetric, holding high values in the direction of Non-Preferred Hand (NPH) to Preferred Hand (PH). Children had got a higher IMTL rather than youngsters, adults and old adults with significant differences in adults.

Keywords: transfer of learning, manual preference, manual dexterity, direction of transfer.

Introduction

Intermanual Transfer of Learning (IMTL) is conceptualized as the ability that enables after practice of a hand in a certain task the easiness of learning of the same task by the untrained hand[4].

Currently, this topic focuses on the quantity of transference between limbs, as learning is considered dependent on the performing hand, due to the learning process which takes place through a set of muscles, which does not happen, necessarily, with the contralateral limb muscle set[5]. Therefore, the aim of this study is to find whether IMTL is symmetric, occurring similarly and independently of the hand that initially learns the task (preferred or non- preferred hand) or asymmetric, being the quantity of IMTL higher in a certain direction.

There is a lack of agreement in several researches about the magnitude of direction of IMTL. Some authors suggest that the process of transfer is symmetric (e.g. Stockel & Weigelt[6] van Mier & Petersen[7]), others report a transfer behavior as being mainly asymmetric (e.g. Kumar & Mandal[8]; Redding & Wallace[9]). To be aware whether IMTL is symmetric or asymmetric upon a theoretical point of view, is to know the role played by the two brain hemispheres in the movement control in a certain task; a practical point of view provides guidelines that might help the *design* of practice improving performance in the acquisition or training of a certain motor skill[10].

Investigations on the transfer mechanisms and adaptation of learning from one hand to another, also including the direction of transfer of PH to NPH, or vice-versa, would enable the identification of brain regions associated with the representation of what is learned during the acquisition process and transfer of learning.

Researches on the lateralization of brain activity during learning have shown a dominance of the left hemisphere, regarding learning sequences, planning and motor control, independently the side of practice (e.g. Grafton, Hazeltine, & Ivry[11]). These outcomes underpin the Callosal Access Model (*Callosal Access*), by Taylor and Heilman[12], one of the three models which explain the bilateral transfer. This model suggests a triggering in the acquisition phase, which does not overlap the activation in the phase of transfer and allows the possibility of brain activation on the left hemisphere regardless the side in usage. Acquisition, whether with the right or the left hand, could activate similar brain regions in the left dominant hemisphere. Therefore, it is possible that some activation in the transfer overlaps brain regions, whose function is self-governing regarding the hand to be used. This model grounds on Liepmann's[13] research, cited by Anguera, Russell, Noll, and Seidler[14], who was the first author to propose the left hemispheric dominance to motor planning in right-handers, and sustains a higher left- hand transfer of learning to the right-hand (right-handers).

Another model that explains the bilateral transfer of learning is the Proficiency Model (*Proficiency Model*)[15], which foresees the change of brain activity, from the phase of learning to the phase of transfer, to similar contralateral brain regions. Motor programs are designed and stored contralaterally to the hand that is being trained. Consequently, this model is unable to explain any overlapping mechanism in the brain activation during the learning and its transfer to the contralateral limb. As the left hemisphere is in dominance, when the right preferred limb motor control is under acquisition a higher transfer will take place to the left non-preferred limb (in right preferred-handed subjects). Transfer to opposite direction will not take place, according to this model.

The third model is the Cross-Activation model (*Cross Activation*)[16], which proposes the bilateral brain activation during acquisition, although without the overlapping of activation in the phase of transfer. This model suggests that during the acquisition with the right hand (preferred) main motor programs are created in the left dominant hemisphere and an "inferior" version is also created in the right hemisphere. Hence, a higher transfer of PH occurs, which mobilizes the superior motor programs for NPH, in comparison to the opposite case.

The performance of motor task and the variables used to assess performance are the correct answer to state that IMTL is whether symmetric or asymmetric, implying a higher transfer to a direction in relation to another. The processes of transfer of learning have been studied through several motor tasks and often involving the research on the direction of that transfer. On the other hand, although those tasks have been preferentially applied to right-handers (RH), researches also involving left-handers (LH) became relevant. Nevertheless, studies remain scarce and despite considering HP, regarding its direction, they investigate also HP in relation to its intensity, comparing Strong Lateralized (SL) and Weak Lateralized (WL) RH and LH subjects.

Another interesting aspect that has been investigated is IMTL in subjects from different nationalities. Few researches have been investigating this factor, but Brandão[17] carried out a research involving old people. Outcomes have revealed that IMTL occurred differently between the Portuguese and the Brazilian nationalities. While the Portuguese youngest old people group presented a significant difference between genders, the Brazilian group evidenced the same difference in the oldest group. The author recommends further investigation having in mind these outcomes. Therefore, it becomes relevant to carry on research on how IMTL occurs in subjects coming from different nationalities. On the other hand, the majority of the referred studies has been researching IMTL in isolated age groups, and direction and magnitude have not been investigated, comparing subjects belonging to different age groups. Under a scientific perspective, researches involving FMD and IMTL become interesting, due to the scarcity of results in this field, thus inhibiting to reach consistent conclusions. This problem demands the following question: What is the direction of IMTL (symmetric or asymmetric), in groups with different gender, age, nationality, different direction and intensity of HP, performing a task involving FMD? The choice of manual dexterity has grounded upon the fact that this capacity, demanding a fast and accurate movement control is requested by the most part of motor learning, whether in school context, in high performance training, or during daily activities. As several researches have proven that motor dexterity is influenced by gender and age (e.g. Carmeli, Patish, & Coleman[18]; Pennathur, Contreras, Arcaute, & Dowling[19]), these variables shall be investigated. Hence, this research aims to analyze IMTL in a FMD task in subjects of different HP (direction and intensity), considering DT, gender, age and nationality.

Methods

Participants

The sample comprised 882 subjects aged between 6 and 95 years old, both genders, being 294 Portuguese from Porto metropolitan area (167 women and 127 men) and 588 Brazilian from city of Rio Branco in the State of Acre (310 women and 278 men), all of them attending Elementary schools, Private Institutions and Public Universities in Porto, Portugal and in Rio Branco/Acre, Brazil. Participants were divided in four age groups: 6-10 years old (250 children); 11-20 years (250 youngsters); 21-59 years (211 adults) and 60-94 years old (171 old people). This classifying of older people met the guidelines of the World Health Organization (WHO), being established according to each nation's socio-economic level. In developing countries older people are considered to be 60 years old or over. Participants belonged to the social-economic level classified as medium and their literacy level was between elementary and academic (in accordance with the Ministry of Education). The sample comprehended 2 Portuguese and 2 Brazilian old people who neither knew how to read and write. In relation to sports practice, 133 Portuguese and 176 Brazilian reported physical practice, even though not systematic or structured. These participants reported practicing once or twice a week, with a 60- minute duration, per session. Reported activities were: walking, hydro gymnastics, working-out, dance and football, among others. Inclusion criteria met the need of functional fitness to perform FMD tests. Participants with mental disability, with superior limb physical disability or presenting inability to take the test were excluded. Participants who practiced professional sports and those who played musical instruments twice or more a week were also excluded, as well as participants practicing structured and systematized physical activities three times a week or more. Subjects who have not finished the assessment were also out. Participants were counterbalanced regarding gender, HP and task starting hand. Data anonymity and confidentiality have been kept.

Instruments and tasks

Hand Preference was assessed through the Dutch *Handedness Questionnaire*[2]. This questionnaire comprehends 10 items comprising simple, unimanual daily life activities. To execute each activity participants were asked to respond if they used the left hand, the right hand or if they had no preference for any of them. Children were asked through objects shown in the questions aiming a better reliability in response. The left hand was given –1, the right hand +1 and the option "any of them", 0. According to van Strien[2] participants were classified as Strong Lateralized Left-Handers (SLLH presenting values between –10 and –8); Weak Lateralized Left-Handers (WLLH, with values ranging between –7 and –4); Ambidextrous (A, values ranging between –3 and 3); Strong Lateralized Right- Handers (SLRH, holding values between +10 and +8) and Weak Lateralized RH (WLRH with values between +7 and +4). This study aimed preferentially the use of HP as a dichotomous variable, classifying as Right-Handers the SLRH and the WLRH participants and as Left-Handers the SLLH, WLLH and A. The outcomes after assessment were: Portuguese, 245 RH (208 SLRH and 37 WLRH) and 49 LH (20 SLLH and 29 WLLH); Brazilian 357 RH (320 SLRH and 37 WLRH) and 231 LH (124 SLLH and 107 WLLH).

FMD was assessed through the Purdue Pegboard Test, model n. 32020 (Lafayette Instruments Company[3]). When applying this test, each participant sat comfortably facing the instrument, which was on an adjustable table, between 71.12 and 81.8 cm height and performed 30 attempts of 30" each, being 5 attempts in the Initial Assessment (IA) (with one of the hands), 20 attempts in Acquisition (AQ) (with the contralateral hand) and 5 attempts in the Final Assessment (FA) (with the initial hand). In each situation (IA, AQ and FA) the number of pins placed in the holes was registered by the prescribed order and placed one by one without stopping the testing time counting if the pin is dropped. In the direction of PH to NPH the participant performed the acquisition with PH and to NPH-PH the participant performed the acquisition with NPH. The percentage of IMTL was estimated as follows: (Seconds spent in FA – seconds spent in IA / seconds spent in IA) x 100.

Experimental procedures

This study aims to be transversal, comparative and descriptive and all experimental procedures conformed to requirements stipulated in the Declaration of Helsinki. The procedures were approved by the Research Ethics Committee of the Faculty of Sports of the University of Porto. A Free and Clarified Consent Term was read and signed by the children's tutors, adults and old people. After, the Dutch *Handedness Questionnaire*[2] assessed HP, and the *Purdue Pegboard Test*[3] evaluated IMTL in a FMD task, as above described.

Variables

The study independent variables were: direction and intensity of HP, direction of transfer, gender, age and nationality. The dependent variable was IMTL in the FMD task.

Statistical analysis

An exploratory data analysis was performed using the software *Statistical Package for the Social Science* (SPSS), version 21.0, with the following objectives: (i) Verify the possible input errors; (ii) spot the diverging information (outliers); (iii) assess the assumptions of normality (through the *Kolmogorov-Smirnov* normality test) and the notion between kurtosis value and its Standard Error (SE) and homoscedasticity (Levene test). Although the assumption of normality has been rejected by the Kolmogorov-*Smirnov t*est, distribution is nearly to normal, thus, this assumption can be maintained due to the sample dimension (N=882). Then, ANOVA 2x2x2x2x4x2 test of direction and intensity of HP, DT, gender, age and nationality was performed, aiming to compare the main effects of IMTL percentage in FMD task. Tukey's test was used in the *Post hoc* analysis. Significance level was set up at 5%.

Results

According to the preset objectives, the following tables present Anova test results regarding factors of direction and intensity of HP, DT, gender, age and nationality in relation to IMTL percentage.

Table 1 – Mean values, standard deviation (SD), mean differences, F, *p* and η_p^2 values of direction and intensity of HP factors, DT, gender, age and nationality in relation to IMTL percentage.

Factors		(Mean ± S)	Mean differences	F	p	η_p^2
Direction HP	RH LH	10.99±10.27 11.67±9.19	.68	.18	.672	.071
Intensity HP	SL WL	11.15±10.17 11.44±9.24	.28	1.16	.281	.190
Direction of Transfer	PH-NPH NPH-PH	10.39±9.42 12.16±10.41	1.77	4.68	.031	.580
Gender	Male Female	11.98±9.92 10.64±9.90	1.34	.12	.722	.065
Age	Children* Young Adult* Old adult	13.18±10.19* 11.62±8.42 10.00±7.22* 11.32±13.68	3.17	1.13	.260	.359
Nationality	Portugal Brazil	10.40±12.06 11.82±8.72	1.43	.00	.936	.051

* See chart 2 from Tukey's *Post hoc test.* RH: Right-Handers. LH: Left-Handers. SL: Strong Lateralized, WL: Weak Lateralized.

Direction and intensity of HP factors have not shown significant statistical effects on IMTL, demonstrating that IMTL values have not differed among the groups under investigation.

Factor DT has revealed a significant statistical effect on IMTL. IMTL has shown to be higher in the direction of NPH - PH rather than in direction PH-NPH.

Factor gender has not revealed significant statistical effects on IMTL, demonstrating that IMTL values have not been different among groups.

Factor age has not shown a significant statistical effect on IMTL. However, *Post Hoc Tukey test* (p= 0.003) has displayed a higher IMTL in children in relation to adults (see Table 2).

Factor nationality has not revealed significant statistical effects on IMTL, evidencing that IMTL values have not differed among groups.

Tukey's Post hoc test has shown a significant statistical effect on age factor. IMTL has shown higher in children (13.18±10.19) than in the other ages (youngsters: 11.62±8.42; adults: 10.00±7.22; old people: 11.32±13.68), dysplaying significant statistical effects between children and adults (p=0.003).

Table 2 – Values of mean differences, standard error and age factor p values, relatively to IMTL percentage of Tukey's Post hoc test.

(I) Age	(J) Age	Mean Differences (I-J)	Standard Error	p
06 – 10 Children	Young (11-20)	1.56	.88	.288
	Adult (21-59)	3.17*	.92	.003
	Old adult (60-95)	1.85	.97	.229
11 – 20 Young	Children (06-10)	–1.56	.88	.288
	Adult (21-59)	1.61	.92	.297
	Old adult (60-95)	.29	.97	.990
21 – 59 Adult	Children (06-10)	–3.17*	.92	.003
	Young (11-20)	–1.61	.92	.297
	Old adult (60-95)	–1.31	1.01	.564
60 – 95 Old adult	Children (06-10)	–1.85	.97	.229
	Young (11-20)	–.29	.97	.990
	Adult (21-59)	1.31	1.01	.564

Concerning interactions, the following statistically significant results were observed: intensity of (HP) x (DT) ($F_{1.788}$=3.937; *p*= 0.048); age x HP intensity x DT ($F_{3.788}$=2.878; *p*= 0.035).

Interaction between the intensity of HP x DT has shown that a major transference has occurred in the direction of NPH - PH in both groups, SL and WL, evidencing that the difference between DT in IMTL percentage is higher in WL subjects rather than in SL, as displayed in figure 1.

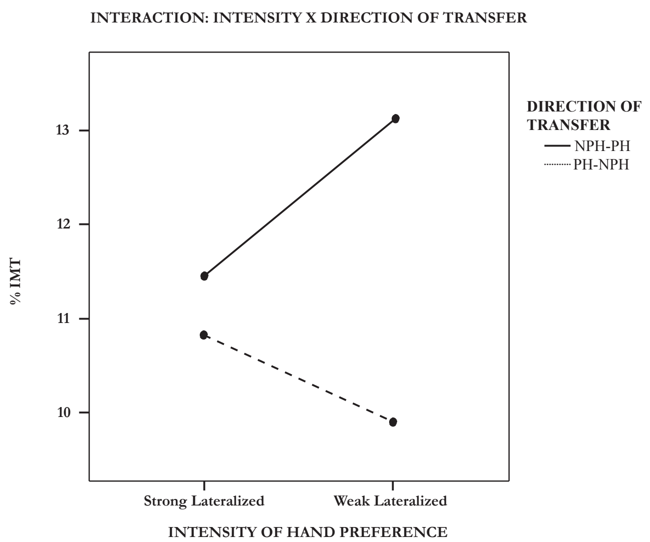

Figure 1 - IMTL. Interaction: Intensity of HP x DT.

Interaction among age x intensity of HP x DT has revealed a statistically significant effect ($F_{3.788}$=2.878; *p*=0.035). To explore this interaction an ANOVA test was taken on factors: age x DT in each intensity of HP and factors of intensity of HP x DT in each age .

The analysis age x DT in each intensity of HP has evidenced a statistically significant result only for the factor age ($F_{3.664}$=2.876; *p*=0.035) in SL subjects. Figure 2 allows to verify that SL subjects present a higher difference between DT in IMTL percentage in children rather than in the other ages and less high in adults. A higher IMTL can be seen in children in direction NPH-PH rather than in direction PH-NPH.

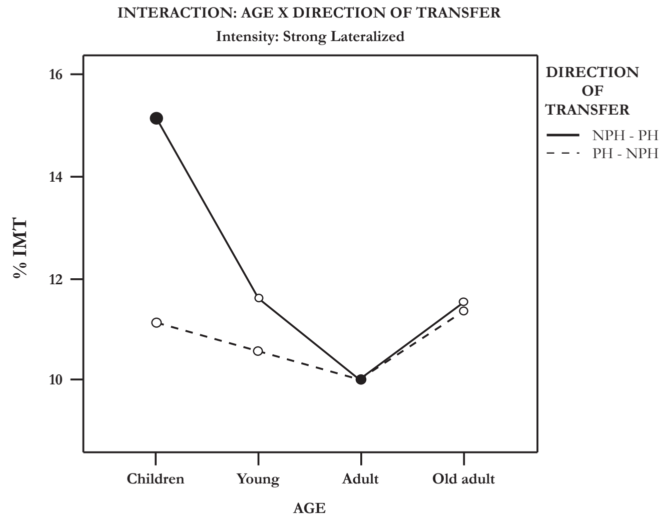

Figure 2 - IMTL. Interaction: Age x Direction of transe

Intensity between HP x DT in each age has displayed statistically significant outcomes only for the factor DT ($F_{1.246}$=6.132; *p*=0.014) in children. Figure 3 shows that a higher IMTL in direction NPH-PH has occurred rather in direction PH-NPH in children, being higher in SL children rather than in WL. These outcomes confirm the ones from the previous analysis.

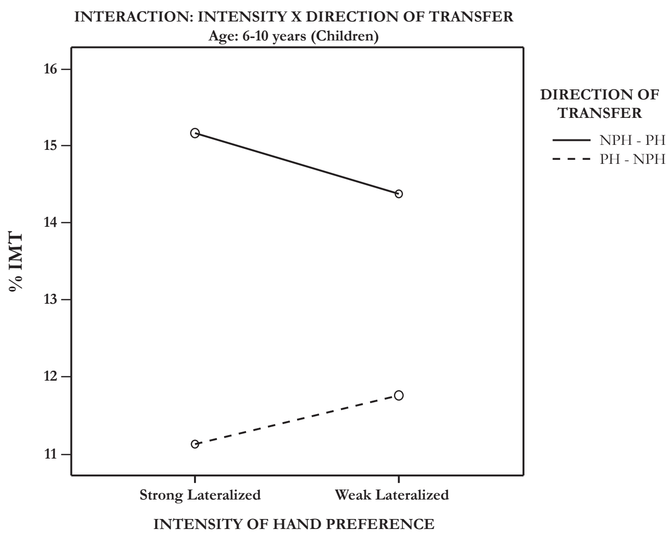

Figure 3 - IMTL. Interaction: Intensity of HP x DT in children. -1440.

Discussion

The main objective of this study aimed the investigation of IMTL in a FMD task in SL and WL subjects of different HP, considering DT, gender, age and nationality.

Direction of Hand Preference

Having in consideration HP (LH and RH), its effect was not visible as the outcomes have shown that IMTL values are equivalent both in LH and in RH. Although the difference between LH and RH has not met statistical meaning, corroborating the results of other investigations (e.g. Carneiro[20]; Triggs, Calvanio, Levine[21], 1997; van Mier & Petersen[7]), values of IMTL observed in LH are higher when compared to RH. Opposing our results, Judge and Stirling[22] have investigated IMTL according to HP and the outcomes have shown LH advantage. Contrarily to this study and confirming ours in what concerns the variable HP the investigation of Maria Madalena Soares Santos, Rodrigues, Freitas, and Vasconcelos[23] observed that HP has not displayed significant effects on IMTL at FMD level, demonstrating that RH and LH do not differ between themselves. RH prefer the right hand to perform their unilateral daily activities, thus revealing that they adapt themselves more rapidly than LH to daily motor tasks. We have noticed that the world favors RH and often LH have to use mostly their NPH in daily manual activities. For this reason, we hoped that IMTL had been higher in LH as they are more bi-hemispheric than RH. However, IMTL was similar between groups. A possible explanation for the absence of these differences connects to the easy understanding of the motor task (reporting to the cognitive explanation of transferring important information related to the objective when performing the task) and to the simple neuromuscular control of the motor program involved (motor program requests simple movements and little degrees of freedom). Consequently, the small motor and cognitive task complexity was insufficient to differentiate the two HP groups.

Intensity of Hand Preference

In relation to the intensity of HP we are able to state that IMTL values do not differ between SL and WL subjects. However, it was expected that IMTL would be higher in SL participants, as they always use right or left hand to perform motor tasks, which would result in a higher quantity of transfer to contralateral hand, due to the higher proficiency, or at least, to the higher practice of preferred hand. However, we have observed no association between IMTL and the intensity of HP, being IMTL values similar in the two groups. We suggest that the experiences in the several daily tasks, which can differ in their specificity between subjects, overlap the intensity of their HP. Due to the scarcity of investigations conducted to research the intensity of HP in IMTL in task of FMD these outcomes are of extreme importance and recommend further researches in IMTL field.

Direction of Transfer

The effect of DT could be seen in the direction NPH-PH. IMTL has shown higher in this direction rather than the opposite, revealing an asymmetric behavior and pointing out that results exhibited higher transfer when the motor task was trained with NPH (acquisition phase). These results are expressively illustrated in the interaction figures, where IMTL is higher in the direction NPH-PH in SL and WL subjects, and they correspond to one of the three models that explain bilateral transfer, underpinning the Callosal *Access*[12] model, previously presented. A possible explanation for the direction of DT had been higher in the direction NPH-PH has its foundation in the fact that being the NPH the one that learns and trains the task, its cognitive involvement (understanding, attention, focus) in performing the task is higher rather than when the PH practices. PH perhaps being the most proficient learns the task more easily, which implies a lower cognitive involvement in the task processing (mainly if this is predominantly a motor task, as it is the *Purdue Pegboard* Test, used in our investigation). When transferring the task to the other hand (NPH), IMTL is reduced due to the weak cognitive involvement of the previous learning task using PH. In contrast, when training hand is NPH, the subject should pay attention, be focused, ought to process cognitively the information during the training or learning process, that is, pay attention to the parameters of movement, such as velocity of execution, commitment between this and the accuracy on placing the pins in the hole, task execution rhythm, strength on the movement or on the perception of distance between pins. When the subject wants to transfer the learning to the other hand (PH), this hand acquires a higher IMTL percentage, as initially a higher cognitive involvement has taken place comparatively to transfer from PH to NPH. Our results corroborate Schmidt and Wrisberg[24], Kumar and Mandal[18] and Senff and Weigelt[25] researches, who have also observed a higher transfer in direction NPH-PH.

Gender

Regarding gender, it can be said that IMTL values are not different between male and female gender**.** While some researches convey the absence of significant differences between genders[7,20,26], other studies establish an interaction between age and gender[27,28]. A research from Santos[28] demonstrates that while in the youngest group female gender has got higher IMTL values than the male gender, in the oldest group the opposite was found. Bazo's study presents different results from Santos[28]: in the male gender, the youngest group presents the highest IMTL percentage and the oldest group displays the lower percentage; the opposite was seen in the female gender. It can be seen that the difference between the age groups is higher in the male gender in relation to female gender. However, our results are not in agreement with these findings. A plausible explanation for the lack of differences between genders in IMTL can be linked to subjects' cultural issues. Probably, daily activities were not sufficiently relevant to influence the magnitude of IMTL, when comparing genders**.**

Age

Regarding age, we have been able to find that children have presented a higher IMTL than youngsters, adults and old people. Findings have shown that the highest IMTL difference occurred between children and adults, with higher IMTL values found in children. Another interesting aspect of our results is related to the interaction between factors, which has revealed a higher IMTL in SL children. Nevertheless, we have noticed that the percentage of IMTL has been diminishing through the age groups, being smaller in adults. These outcomes confirm what literature suggests, that is, with aging functional losses are more noticeable and manual dexterity declines, revealing itself slower in the oldest subjects[29]. This fact embodies, also, a certain loss of IMTL capacity. Yet, our research has not presented significant differences between adults and old adults, still, old adults presented IMTL values slightly higher. Researches by Cherbuin and Brinkman[30], Byrd, Gibson, and Gleason[31] and Uehara[32] sustain that IMTL capacity increases with age, having authors interpreted this result through mental and physical maturation development. An investigation by Brandão[17] has shown that old people over 80 years old presented a higher IMTL than the old people belonging to 60-69- year old group, as well as those grouped in 70-79 years old. Our outcomes have not confirmed those found in these studies, as we have observed a decreasing of IMTL with age, although being significant only when comparing children and adults.

Nationality

Concerning nationality, results have shown no difference between Portuguese and Brazilian, both with similar values of IMTL. Despite the difference between Portuguese and Brazilian has not attained statistical significance, IMTL values found in Brazilian are higher relatively to values found in Portuguese. Brandão[17] has investigated IMTL in a task of FMD in a sample comprising 154 Brazilian and Portuguese old people. Results have not displayed a significant statistical effect regarding factor nationality, despite the author has verified a slight Brazilian superiority. Notwithstanding, the importance of this slight superiority due to the lack of statistical outcomes, the author referred that perhaps, in a larger sample, the cultural factor could have some effect upon IMTL. Underpinning this suggestion, Brandão[17] refers that in the North region of Brazil not only the farming work, plantation and crop still remain, for producing flour, but also hunting and fishing. These works require manual abilities, both unilateral and bilateral, the last involving limb motor actions in simultaneous or alternate movements. All these tasks of Brazilian daily routine would justify, probably, an increasing on IMTL with statistical significance, comparatively to Portuguese, if both researches had presented a larger number of participants.

Further investigation is advised focusing on this topic, approaching other analysis types, such as: investigate IMTL in motor ability of Gross Manual Dexterity. Although included within a more comprehensive capacity of manual dexterity, holds its own particularities. Finally, studies should focus on clarification of the behavior of IMTL in relation to HP across age, comprising longitudinal investigations.

Conclusions

Responding to the initial question, we may conclude that in this investigation IMTL was asymmetric in direction NPH-PH, that is, training with PH has benefited the acquisition with NPH. Factor interaction has shown that IMTL in direction NPH-PH is higher in WL subjects rather than in SL. Nonetheless, we have not found IMTL differences between RH and LH, SL and WL subjects, between male and female gender, Portuguese and Brazilian. Furthermore, we have noticed that children had got a higher IMTL in relation to youngsters, adults and old people, with significant differences in adults.

Some limitations were found when this investigation was structured. We have verified a scarcity in references about our specific topic in the literature review, mainly when associating IMTL to HP and nationality. In general, all researches have assessed different factors from those we aimed to investigate, which has conditioned our discussion, making our work more relevant than the expected. Furthermore, the framework applied in this investigation, due to its countless repetition number, hampered subjects' participation preventing them to complete the motor test, thus being excluded from the investigation. Further studies are needed to investigate other types of analysis: IMTL in the motor skill of GMD, which despite included in the broadest capacity of Manual Dexterity, possesses its own particularities. Finally, further investigation is recommended to clarify IMTL behavior to HP along age, involving longitudinal researches.

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Manuscript received on November 12, 2015
Manuscript accepted on September 28, 2016