A mobile app for characterizing the aging of human motor performance

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Introduction

Studies in the literature have shown that motor performance changes across the life span, i.e. it improves from childhood to young adulthood and then it gets worse with aging [3,4]. Paper-and-pencil tests, such as the Trail Making [5] and the Spiral Drawing [6] tests, are a traditional method that neurologists use to assess patients’ motor skills or impairments. The advent of technologies such as digitizing tablets or touchscreens offered neurologists new, more convenient and more precise methods to carry out the above mentioned and other motor tests. The computational capabilities of current smartphone allow to process locally the collected motor skills data and to provide users with an assessment of their motor performance. A tablet version of the Spiral Drawing Test has been proposed [14] on the Android platform, while the Java-based app for Windows Mobile PDAs [15] included also the Finger Tapping Test [7]. Recently, smartphone-based apps that contain the Finger Tapping Test have been employed in the studies described in [16,17].

We propose a mobile app (called “MotorBrain”) for all major mobile platforms (Android, iOS and Windows Phone) that is able to turn millions of smartphones and tablets available to the general public into data collection and assessment tools. MotorBrain provides the user with different versions of Trail Making and Finger-Tapping Tests. We designed the interface of the app to make it easily usable by different kinds of patients as well as healthy individuals and let them interact more naturally and directly with the tests by using their finger. A large database of such data could be used for research on the aging of the population’s motor performance and, in particular, for investigating the physiological aspects that are involved in the aging process, which have been identified only recently [18]

Materials and Methods

MotorBrain was developed in Unity [19] for all three major mobile operating systems (Android, iOS and Windows Phone). The app offers six motor tests organized in three categories based on the characteristic of motor control on which they primarily focus, i.e. accuracy, speed, or reaction time. Each category contains two motor tests that are presented to the user in a fixed order and require to be performed twice, first with user’s dominant hand and then with the non-dominant one. Each of the six motor tests requires three repetitions of a task with the same hand to produce an assessment. Once users have completed the three trials, the app displays an assessment of motor performance concerning the test and the hand used (fig.9). The app offers four Trail Making Tests (**CIRCLE-A**, **SQUARE**, **PATH**, and **CIRCLE-S**) and two Finger-Tapping Tests (**TAPPING2** and **TAPPING4**). **CIRCLE-A (accuracy):** The task area (fig. 2) contains a ring (thickness=0.5 cm, diameter of outer circle=4 cm). Users have to move their index finger on the ring, following it all over its length once and without ever lifting the finger. The starting point and the direction of movement depend on the hand with which the user has to perform the test. A trial ends when the user has covered a distance equal to the mean between the perimeter length of the outer and inner circle of the ring or (s)he has lifted the finger from the screen for more than 0.15 s. **SQUARE (accuracy):** The task area (fig. 3) contains a square frame (thickness of the frame=0.5 cm, side of the outer square=4 cm). Users have to move their index finger on the frame, following its entire length once and without ever lifting the finger, as in CIRCLE-A. **PATH (speed):** the task area contains a path (fig. 4) composed by four connected lines (line thickness=0.6 cm, length of each line=3.72 cm, angle between each pair of connected lines=19.8°. Users have to move the index finger from the start to the end of the path as fast as possible within a 5-second interval. The timer starts when the user touches the starting point and time remaining is displayed by a decreasing green bar at the top of the task area; a trial ends when time expires, when users lift the finger from the screen for more than 0.15 s or when they have covered a distance equal to the path. **CIRCLE-S (speed):** the graphic elements of this test (fig. 5) are the same of CIRCLE-A, but the thickness of the ring is larger (0.7 cm). Users have to move the index finger over the ring following its entire length as many times as possible during a 7-seconds interval. The timer starts when the user touches the starting point and time remaining is indicated as in PATH. A trial ends when time expires or when users lift the finger from the screen for more than 0.15 s. **TAPPING2 (reaction time):** the task area (fig. 6) contains two aligned round buttons (diameter=1.6 cm); only one button is enabled at any time. The enabled button is visually highlighted by color as well as a black viewfinder. Users have to tap the highlighted button trying to hit the center of the viewfinder with the index finger and have to tap on as many highlighted buttons as possible over a 10 seconds interval. **TAPPING4 (reaction time):** the task area contains four buttons (fig. 7) and only one of them is highlighted at any time. Tapping a highlighted button moves the highlight to another button, randomly selected. Users have to tap on the center of as many highlighted buttons as possible over a 10 seconds interval.

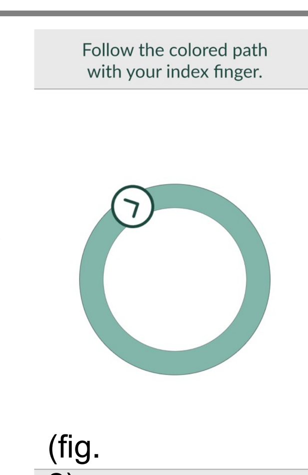
Results

For each motor test, the assessment shown to the user is the mean of the three values of the variable assessed with the three trials. Participants (N=133, 67 M, 66 F) were recruited on a voluntary basis through direct contact, asking them if they were willing to try a mobile app that offers an assessment of their motor performance. All of them were right-handed; none of them suffered from: (i) headache or migraine, or (ii) any illnesses or pain at the wrist, elbow or hand. Moreover, none of them were under the effects of substances such as drugs or alcohol that could impair performance. Then, they were further divided into two groups (Young, Old) based on their age (<= 30 years, >=50 years, respectively). The Young group consisted of 68 participants (39 M, 29 F) whose age ranged from 18 to 30 (M=22.97, SD=2.56). The Old group consisted of 65 participants (28 M, 37 F) whose age ranged from 50 to 75 (M=56.68, SD=6.33). When performing the test with one hand, they had to keep the smartphone in the other hand; participants did not receive any previous training or illustration of the app from the experimenter: this was done to check that the tutorial and the user interface were clear, intuitive and immediately usable as planned. Assesment variabiles:

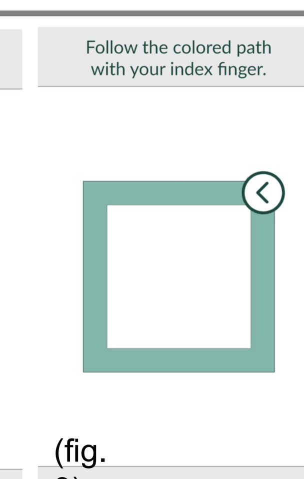
SA (Shape Accuracy): distance covered by the user with the index finger on the ring (CIRCLE-A) or the frame (SQUARE) expressed as a percentage of the target distance, **SGE (Speed on Graphic Element):** mean speed (in cm/s) of the user’s finger when performing the required movements, calculated considering the amount of distance covered on the ring in CIRCLE-S and on the path in PATH, and time (s)he spent in performing the movements, **STA (Speed on Task Area):** this variable is the mean speed of the user (in cm/s) calculated considering the amount of distance covered inside the entire task area, **TA (Tap Accuracy):** the total taps made by the user and for each tap the weight value can be 1, 2, or 5 depending on whether the user tapped the external, middle or central area of the viewfinder, respectively, **RT (Reaction Time):** mean of all the reaction times (in seconds), i.e. time elapsed between the appearance of a highlighted button on the screen and user’s tapping on that button during the trial. The table indicates also the results of the non-parametric W*ilcoxon signed-rank test* we employed to assess the statistical significance of differences between the two groups, since none of the assessed variables follow a normal distribution.

Since participants in the Old group did not experience problems when using the app, results suggest that MotorBrain can be suitable for use by older adults who are in general less familiar with smartphones than younger people. Moreover, a recent market research [22] revealed that the gap between people over-55 and younger generations in terms of smartphone penetration is going to decrease in the next few years.

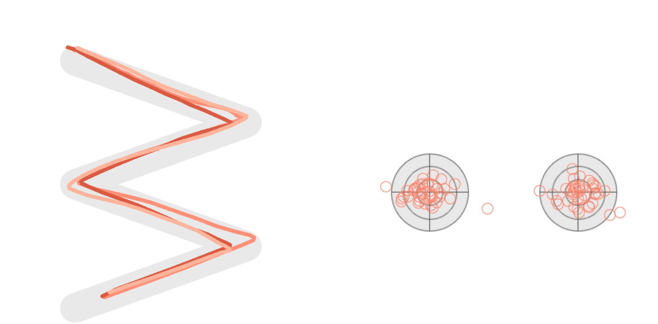
Accuracy was lower for the Old group than the Young group on those tests where the requirement was accuracy, i.e. CIRCLE-A and SQUARE. This result is consistent with the decline in sensorimotor control and functioning that comes with aging [4], which might include a deterioration of spatial coordination of finger and wrist movements [23].



(fig. 2)

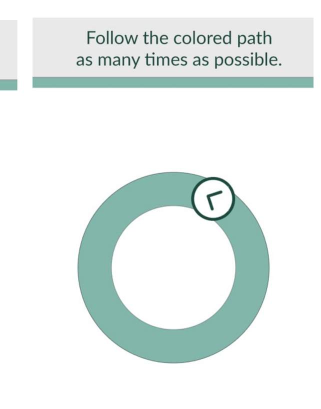


(fig. 3)



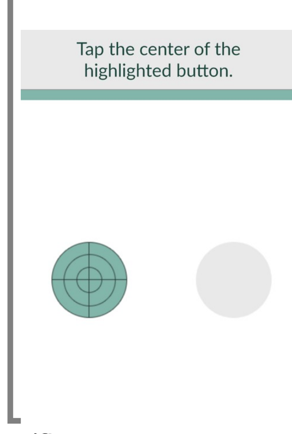
In the tests which focused on speed and reaction time, the Old group performed worse than the Young group.

(fig. 4)

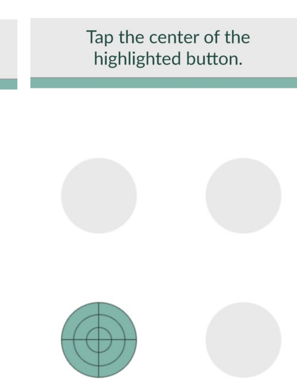


(fig. 5)

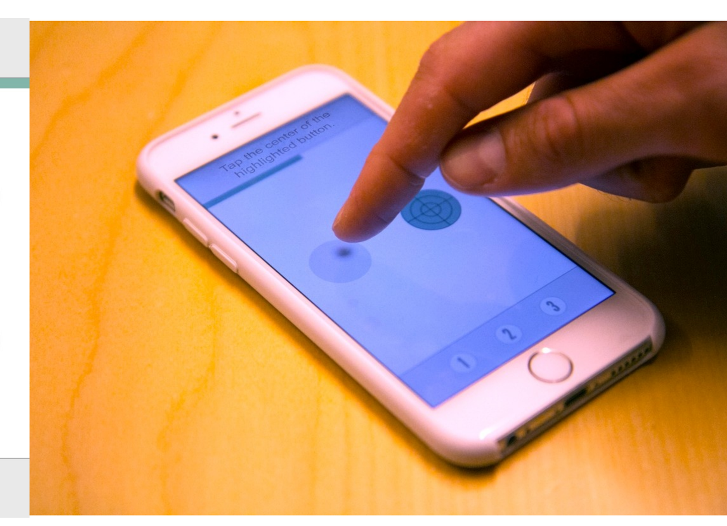
The graphic elements on which the user performed the task are displayed in grey. For PATH, the orange lines show user movements. In this example, three different trials are shown. For TAPPING2, the orange dots indicate where the user tapped on the screen.

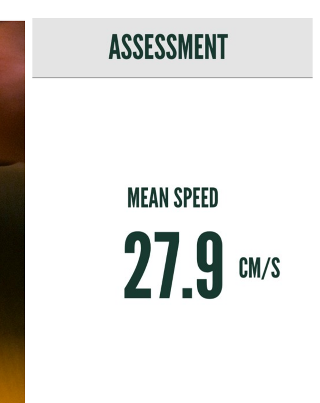


(fig. 6)



(fig. 7)





(fig. 9)

These results can be explained by the loss of performance of the central and peripheral nervous systems and of the neuromuscular system that occur with aging [4,21,24,25]. The reduction in speed and the increase in reaction time in the Old group can also explain the fact that the second requirement, i.e. accuracy, was higher for the Old group in the PATH, CIRCLE-S and TAPPING2 tests, while no differences were found between the two groups in TAPPING4. Indeed, by slowing their movements, participants in the Old group could have performed a repetitive task or followed a shape more accurately. In the case of a less predictable task that can be more prone to errors, i.e. TAPPING4, slower movements could have helped the Old group focus on the center of each highlighted button and thus maintaining the same level of accuracy than younger participants.

Test	variable	Young group	Old group	Wilcoxon test
Circle-A	SA	(194) 0.930 +/- 0.13	(194) 0.890 +/- 0.14	r = 0.21 p < 0.001
Square	SA	(204) 0.940 +/- 0.11	(196) 0.870 +/- 0.15	r = 0.33 p < 0.001
Path	SA	(215) 0.860 +/- 0.06	(214) 0.870 +/- 0.06	r = 0.12 p < 0.05
	SGE	(215) 10.55 +/- 4.63	(214) 7.880 +/- 3.35	r = 0.29 p < 0.001
	STA	(215) 10.59 +/- 4.62	(214) 7.970 +/- 3.30	r = 0.28 p < 0.001
Circle-S	SA	(181) 0.800 +/- 0.16	(180) 0.890 +/- 0.12	r = 0.31 p < 0.001
	SGE	(181) 14.98 +/- 5.64	(180) 11.86 +/- 5.37	r = 0.30 p < 0.001
	STA	(181) 19.90 +/- 5.64	(180) 13.98 +/- 5.37	r = 0.36 p < 0.001
Taping2	TA	(209) 0.810 +/- 0.14	(196) 0.850 +/- 0.12	r = 0.12 p < 0.05
	RT	(209) 0.200 +/- 0.12 ms	(196) 0.350 +/- 0.23 ms	r = 0.42 p < 0.001
Tapping4	TA	(201) 0.780 +/- 0.13	(192) 0.760 +/- 0.13	r = 0.33 p = n.s.
	RT	(201) 0.500 +/- 0.05 ms	(192) 0.630 +/- 0.26 ms	r = 0.54 p < 0.001

Conclusion

By contrasting performance assessment variables obtained with MotorBrain in the two age groups, we obtained results that are consistent with those of studies conducted with digitizing tablets, desktop computers, or ad-hoc surfaces, e.g. [13,20,21]. The obtained results show that the data collected through the MotorBrain app is suitable to make meaningful distinctions among different kinds of performance, such as **accuracy**, **speed** and **reaction time**, and is able to highlight performance differences due to aging. This is promising with respect to the next goal of the research, i.e. to collect large datasets of human motor performance by making the MotorBrain app freely available to the general public. We will explore if an instrument that is able to detect motor performance differences due to aging such as MotorBrain could be useful to detect the presence of movement disorders when they are still in a subclinical stage and cannot be detected by physician’s clinical observation.

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