The Virtual Egg Test

The Virtual Eggs Test (VET) used in this study as starting point is presented in Controzzi et al.[36] and was aimed at evaluating both the fine and gross hand dexterity. During the test, participants are asked to transport fragile objects over a barrier as fast as possible and without breaking them. The test has been exploited to evaluate hand dexterity in amputees using myoelectric hand prostheses[36]. After interdisciplinary meetings involving engineers, medical doctors and physiotherapists, the components of the VET have been refined to improve the capability of the test to evaluate hand dexterity in subjects with motor impairment resulting from central nervous system injury. Specifically, the test aims to assess the ICF construct Activity subdomain Mobility.

The components of the Virtual Eggs Test (VET) are:

(1) fragile objects of roughly cubic shaped, called Virtual Eggs (VEs);

(2) a platform to guide the task of transporting the VEs from one point to another;

(3) a dedicated software to acquire data.

Virtual Eggs. The VEs are parallelepipeds with dimensions 45.5 x 41 x 45.5 mm weighing ~90 g. When the grasping force exceeds the pre-set break threshold, the walls collapse and the object “breaks” reversibly. The gripping walls of the VE are covered with sandpaper (grit 240) to minimize the variability in friction The kit comprises of 22 VEs with different fragilities. The break thresholds (BT) in N and their values normalized to the weight and the coefficient of friction of each VE (*f*) according to equation (1) are reported in Table 1.

$$\emptyset_{VE} = \frac{2 \times \mu \times BT}{W} \quad (1)$$

Where: μ = VE friction coefficient, BT = break threshold (N), W = weight (N)

Table 4. Break thresholds of the 22 Virtual Eggs (VEs).

Virtual Eggs	BT (N)	$Ø_{VE}$ (N/N)
VE #1	0.33	0.97
VE #2	0.45	1.46
VE #3	0.63	1.95
VE #4	0.83	2.44
VE #5	0.95	2.93
VE #6	1.28	3.66
VE #7	1.43	4.39
VE #8	1.62	4.88
VE #9	1.93	6.10
VE #10	2.22	6.83
VE #11	2.42	7.32
VE #12	2.80	8.54
VE #13	3.19	9.76
VE #14	3.62	10.98
VE #15	4.00	12.20
VE #16	4.38	13.41
VE #17	4.78	14.63
VE #18	5.45	17.07
VE #19	6.15	19.51
VE #20	7.30	21.95
VE #21	8.04	24.39
VE #22	9.48	28.05

BT = break threshold expressed in Newton (N); $Ø_{VE}$ = break threshold normalized

Positioning platform and software. A platform (sized 31.5 x 48.5 cm) is used to guide the task. The platform presents two positioning areas for the VE (Egg Placer), 20 cm apart and separated by a 6 cm high barrier. The HOME position for the hand (12 cm for the long side and 6 cm for the short side) is placed in the middle of the platform, on the side facing the subject performing the test. The three areas are highlighted with red frames and are sensitive to touch: the contact of the hand or the VE returns feedback through LED, visible

to both the examiner and the participant, and provides a trigger to the software for computing the timeframes during the execution of the task. Before starting, the platform is placed on the table and connected to the software which guides the examiner during the test and provides feedback if the participant does not follow the procedure of the test correctly.

Protocol. The positioning platform is placed on the table and connected to the PC where the software is running. The participant is seated in front of the positioning platform, with the hand of the examined arm placed on the HOME position. The height of the seat is adjusted so that when his/her hand lay on the platform the forearm is horizontal. The test always starts with the VE placed on the positioning area of the side assessed. During the test, the participant is asked to transfer the VE selected by the examiner without break it and as fast as possible from one Egg Placer to the other over the barrier. This transfer is repeated for five times. Each transfer is composed of three steps:

(1) Reaching phase: Starting with the hand on the HOME position, the participant reaches the VE and grasps it with a pinch grasp.

(2) Flight phase: The participant lifts the VE from the Egg Placer, transports it over the barrier and places it in the opposite Egg Placer.

(3) Returning phase: The participant returns the hand on the HOME position.

When the VE is broken or is unintentionally released, the examiner notes it on the software interface and invites the subject to continue with the remaining transfers. The trial is considered as “successful” when the participant can complete at least 4 transfers without breaking the VE. Fifteen trials are performed with progressively more fragile VEs, each consisting of 5 transfers of the VE. The first VE to be manipulated is the most robust one (VE22), and the following ones are selected according to an adaptive up/down method based on the performance of the participant. In case of success (successful transfers ≥4),

the VE with three-units lower breakage threshold is used for the next trial. Otherwise, the VE with a one-unit higher breaking threshold is used.

Before starting a trial, the participant is asked to voluntarily break the proposed VE up to 4 times to familiarize with its fragility. Moreover, his/her fingertips are sprinkled with chalk dust to standardize the friction coefficient throughout the test. One-minute rest is taken after each trial.

Measures

For each trial, the software collects the time of the flight phase, the total time of the transfer (i.e., reaching phase + flight phase + return phase) and the number of correct transfers.

VET adaptations for assessment of hand dexterity in stroke survivors

In order to perform the pilot, the following changes were made to the Virtual Eggs Test (VET) with respect to the last study on amputees presented in Controzzi et al.[36]:

1. A sensorized plate replaces the start/stop button which required the subject to press the start/stop button with some force twice between VE transports (once to end the previous transport and once to start the next one). This improvement facilitates the task for post-stroke survivor.
2. The platform has been equipped with sensors the two Egg Placers and with LED signaling their activation. Subjects with stroke outcomes might suffer from incoordination that hinders the correct ending positioning of the VE. Thus, these modifications allow both the participant and the examiner to recognize whether the transfer is completed correctly. In addition, these sensors can be exploited to automatically measure the time for each phase of the transport.

3. A procedure to standardize the coefficient of friction between fingers and VE is added, i.e. the VE grip surfaces are covered with sandpaper and participants dips their fingertips in magnesite power before each trial. These two steps allow for reducing the effect on the grip due to different skin conditions (e.g., sweat or sebum) between participants.
4. A broader set of VEs is exploited during the pilot with the aim of finding the suitable range of fragility for the VEs specific to post-stroke participants. The execution protocol of the pilot differs from the one Controzzi et al.[36] since features an adaptive procedure to determine which VE must be manipulated. This allowed to reduce the time of the test, without affecting the quality of the acquired data.