EFFECT ON MANUAL SKILLS OF WEARING INSTRUMENTED GLOVES DURING MANIPULATION

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ABSTRACT

Instrumented gloves are motion capture systems that are widely used due to the simplicity of the setup required and the absence of occlusion problems when manipulating objects. Nevertheless, the effect of their use on manipulation capabilities has not been studied to date. Therefore, the aim of this work is to quantify the effect of wearing CyberGlove instrumented gloves on these capabilities when different levels of precision are required. Thirty healthy subjects were asked to perform three standardised dexterity tests twice: bare-handed and wearing instrumented gloves. The tests were the Sollerman Hand Function Test (to evaluate capability of performing activities of daily living), the Box and Block Test (to evaluate gross motor skills) and the Purdue Pegboard Test (to evaluate fine motor skills). Scores obtained in the test evaluating fine motor skills decreased by an average of 29% when wearing gloves, while scores obtained on those evaluating gross motor skills and capability to perform activities of daily living were reduced by an average of 8% and 3%, respectively. The use of instrumented gloves to record hand kinematics is only recommended when performing tasks requiring medium and gross motor skills.

1. INTRODUCTION

Instrumented gloves are motion capture systems widely used due to the setup simplicity and the absence of occlusions when manipulating objects (common drawback in optical systems). They have been applied for different purposes in biomechanics: in hand kinematics applied for patients' functional assessments (Gracia-Ibáñez et al., 2017; Schreck et al., 2018), sign language recognition (Sarawate et al., 2015), precision gesture control in surgery (Itkowitz et al., 2018; Lemos et al., 2017), simulation (Nogueira et al., 2019; Sancho-Bru et al., 2014), validating other motion data systems (El-Sawah et al., 2007; Glauser et al., 2019), and for characterising hand dynamics combined with EMG recording (Jarque-Bou et al., 2018; Naik et al., 2014; Stival et al., 2019). Some of these applications only use joint angles, while others also consider joint velocity and acceleration. The analysed tasks covered a wide range of activities with different manipulation precisions, from fine to gross manipulations, and also non-manipulative activities. Nevertheless, work gloves affect grasping and manipulation capabilities, which leads us to wonder about the effect of using instrumented gloves on manual skills such as CyberGlove (CyberGlove Systems, San Jose, CA, USA), the most widely used in biomechanics (Jarque-Bou et al., 2019; Jarrassé et al., 2014; Yun and Freivalds, 1995).

In order to evaluate work gloves effects on dexterity, some studies propose indicators such as the index of dexterity in manipulation (using O'Connor and Purdue Pegboard tests (Bensel, 1993; Berger et al., 2009; Johnson and Sleeper, 1986) or other non-standardised tasks such as pegboard tasks, block manipulation, rope knotting or assembly tasks (Bishu et al., 1993; Muralidhar et al., 1999)), touch sensitivity using the Semmes-Weinstein monofilament test set (Dianat et al., 2012, 2010), grip strength (Dianat et al., 2012, 2010; Muralidhar et al., 1999; Torrens and Newman, 2000; Willms et al., 2009) or range of motion (Bellingar and Slocum, 1993). These studies show that using work gloves reduces dexterity (Bishu et al., 1993; Dianat et al., 2010; Johnson and Sleeper, 1986; Muralidhar et al., 1999). Such reductions vary from a slight decrease in dexterity test scores (Nelson and Mital, 1995) to increases of up to 87% in the time of accomplishment of the test (Torrens and Newman, 2000), depending on the glove characteristics. Dexterity reduction depends on the glove material and thickness (Banks, 1979; Bensel, 1993; Muralidhar et al., 1999; Plummer et al., 1985), and is greater for stiff and bulky materials such as leather (Torrens and Newman, 2000) than for thinner materials such as latex (Nelson and Mital, 1995).

Given the effects of using work gloves reported in literature, the aim of this work is to quantify the effect of using a CyberGlove on manual skills when performing tasks requiring different degrees of precision, which is still unknown. This will help establishing the limitations of using the glove in biomechanics, especially in research applications where specific kinematic parameters are quantified. The analysis was performed using three different standardised tests: the Box & Block Test (BBT), which evaluates gross motor skills; the Purdue Pegboard Test (PPT), which evaluates fine motor skills, and the Sollerman Hand Function Test (SHFT), which focuses on the capability to perform activities of daily living (ADL).

2. METHODS

2.1. SUBJECTS

Thirty healthy adult subjects (16 male, 14 female; 37.83±8.07 years of age) participated in the experiment, approved by the University ethics committee, after signing their written informed consent. Subjects' laterality (27 right-handed and 3 left-handed) was determined using the Edinburgh Handedness Inventory (Oldfield, 1971).

2.2. MATERIAL

One left- and one right-hand CyberGlove were used, together with the kits for the three standardised tests (Figure 2): BBT (Mathiowetz et al., 1985) to evaluate gross motor skills, PPT (Tiffin and Asher, 1948) to fine motor skills and SHFT (Sollerman and Ejeskär, 1995), which evaluates the capability to perform ADL. CyberGlove is made of a synthetic elastic mesh fabric on the palm side, and a denser synthetic elastic fabric on the back in which the 18 resistive bend-sensors and the wiring are embedded. Following the manufacturer's instructions, a thin nylon inner glove is worn to keep the CyberGlove clean and in good condition. The tips of the fingers are covered only by the inner glove (Figure 1). The CyberGlove is worn and secured with a Velcro strap around the wrist. An elastic band around the wrist, commonly used during recordings, was used to ensure a better fit of the wrist sensors.

Figure 1: Dorsal and palmar views of the CyberGlove instrumented glove used in the experiments.

Note that gloves were not acquiring data during the tests, as our aim was to compare just the scores of the dexterity tests while wearing gloves and bare-handed.

2.3. EXPERIMENTS

Each subject performed the three tests twice (bare-handed and wearing the gloves on both hands), the order being randomised for each participant. The experiment was divided into two sessions, in order to prevent subjects from getting tired. Thus, the BBT and PPT tests were conducted in the first session and the SHFT during the second session. Each test was performed following its standardised instructions. The BBT (Figure 2a) comprises one trial for each hand, in which the subject has to pass wooden blocks from one box to another within 60 seconds (Mathiowetz et al., 1985). The PPT (Figure 2b) comprises four trials: the first three trials consist in putting pins into holes on a board within 60 seconds (with the right hand, the left hand and simultaneously with both hands), and the fourth consists in assembling pins and washers with both hands (Tiffin and Asher, 1948). The SHFT (Figure 2c and Figure 2d) involves performing 20 tasks that are representative of ADL, following the operator's instructions, which include whether subjects have to use both hands or only the dominant one (Sollerman and Ejeskär, 1995). The subjects were asked to perform all the tests at the maximum possible pace, but abiding by the test rules.

Figure 2: The different tests performed in the experiment. (a) Box & Block Test, (b) Purdue Pegboard Test, (c, d) Sollerman Hand Function Test.

2.4. DATA ANALYSIS

Results from the tests were measured according to their standardised scorings:

- BBT: blocks passed in each trial.
- PPT: pieces assembled in each trial.
- SHFT: each task is assigned a five-level score according to the type of grasp used, the level of difficulty observed and the time of accomplishment of the task (4 when the accomplishment is as expected, 0 when the task is not performed). A global score is computed as the sum of these 20 scores.

The reductions in scores due to the instrumented gloves were computed for each subject and trial. Descriptive statistics are presented. Seven repeated-measures ANOVAs were performed on the scores of each BBT and PPT test, and on the global score of the SHFT. In all cases, the factor was the use of gloves, to determine its effect on the manual skills assessed by each test. The dependent variables in the seven ANOVAs were BBT score with right hand, BBT score with left hand, PPT score with right hand, PPT score with left hand, PPT with both hands and SHFT global score.

Furthermore, a detailed analysis of the SHFT tasks was performed through their individual scores and times of accomplishment. Twenty repeated-measure ANOVAs, one for each task, were performed on scores and times as dependent variables, again with the use of gloves as the factor. Moreover, score variation and time increase percentages when using gloves were computed for each task.

3. RESULTS

Table 1 presents the descriptive statistics (mean and standard deviation) of the scores and their reductions for BBT, PPT and SHFT trials. Significant differences from the ANOVAs are marked. As expected, scores when wearing gloves are lower than those achieved without them. The seven ANOVAs for the test scores were significant (bilateral asymptotic significance ≤0.01), showing that the use of gloves affects all types of dexterity analysed.

Table 1: Mean (SD) scores and mean (SD) reduction of scores obtained for BBT, PPT and SHFT. Tests "PPT Both 1" when putting the pins in the pegboard with both hands simultaneously, and "PPT Both 2" when performing the assembly task (both hands). Tests with significant differences (sig.≤0.01) in the repeated measures ANOVAs have been marked (**).

Test	Score without glove	Score with glove	Score reduction (%)
BBT Right**	80.23 (8.46)	74.23 (9.55)	7.32 (9.73)
BBT Left**	76.77 (7.24)	70.27 (7.56)	8.37 (6.30)
PPT Right**	16.93 (2.16)	12.73 (2.16)	24.47 (11.17)
PPT Left**	15.17 (2.00)	11.73 (1.89)	22.16 (11.91)
PPT Both 1**	25.40 (3.33)	18.20 (3.69)	27.75 (14.91)
PPT Both 2**	44.13 (6.86)	25.57 (8.34)	41.76 (18.72)
SHFT**	74.07 (1.70)	72.07 (2.13)	2.68 (2.79)

Table 2 presents the descriptive statistics for the individual scores of the SHFT tasks. Significant differences from the ANOVAs are marked. All the tasks with significant differences presented a decrease in scores when performed with gloves.

Table 2: Mean (SD) scores obtained in each SHFT task and percentage of score difference (negative values for decrease in dexterity with gloves). Tasks with significant differences (sig.≤0.01) in the repeated measures ANOVAs have been marked (**).

ID	Task	Score without glove	Score with glove	Score difference (%)
1	Pick up coins from flat surface, put into a purse mounted on wall	4.00 (0.00)	3.87 (0.43)	-3.33 (10.85)
2	Open/close zip	4.00 (0.00)	4.00 (0.00)	0.00 (0.00)
3	Pick up coins from purses**	3.93 (0.25)	3.37 (0.67)	-13.89 (18.87)
4	Lift wooden cubes over edge 5cm in height	4.00 (0.00)	4.00 (0.00)	0.00 (0.00)
5	Lift iron over edge 5cm in height	3.93 (0.36)	3.93 (0.36)	+1.67 (20.69)
6	Turning screw with screwdriver	3.87 (0.51)	4.00 (0.00)	+6.66 (25.37)
7	Pick up nuts and screw on bolts**	3.47 (0.51)	2.90 (0.61)	-15.00 (21.37)
8	Put key into lock, turn 90 degrees	4.00 (0.00)	4.00 (0.00)	0.00 (0.00)
9	Turn door-handle 30º	3.93 (0.36)	4.00 (0.00)	+3.33 (18.25)
10	Unscrew lid of jars	2.73 (0.98)	2.87 (1.01)	+8.33 (32.38)
11	Do up buttons**	3.90 (0.30)	3.37 (0.49)	-13.05 (15.11)
12	Put on tubigrip stocking on the other hand	4.00 (0.00)	3.93 (0.25)	-1.67 (6.34)
13	Cut play dough with knife and fork	4.00 (0.00)	3.97 (0.18)	-0.83 (4.56)
14	Write with a pen	4.00 (0.00)	4.00 (0.00)	0.00 (0.00)
15	Fold sheet of paper and put into envelope**	3.80 (0.41)	3.13 (0.57)	-16.67 (17.51)
16	Put a paper-clip on an envelope	4.00 (0.00)	4.00 (0.00)	0.00 (0.00)
17	Lift telephone receiver, put to ear	3.93 (0.36)	4.00 (0.00)	+3.33 (18.26)
18	Pour water from carton	2.10 (0.40)	2.13 (0.43)	+3.33 (22.49)
19	Pour water from jug	4.00 (0.00)	4.00 (0.00)	0.00 (0.00)
20	Pour water from cup	2.47 (0.86)	2.60 (1.07)	+10.00 (46.23)

Table 3 shows the detailed analysis for the time of accomplishment of each SHFT task. Again, significant differences in the ANOVAs are marked. When wearing gloves, times were higher in all the tasks and significant differences were found in all the tasks except two.

Table 3: Mean (SD) time of accomplishment (in seconds) of each SHFT task and mean (SD) percentage of time increase. Significant differences after applying a repeated measures ANOVA were marked ((*) when sig.≤0.05, (**) when sig.≤0.01).

ID	Task	Time of accomplishment without glove (sec)	Time of accomplishment with glove (sec)	Time increase (%)
1	Pick up coins from flat surface, put into a purse mounted on wall**	7.20 (1.69)	13.40 (8.14)	101.51 (163.75)
2	Open/close zip**	7.27 (1.74)	8.60 (1.96)	20.74 (23.55)
3	Pick up coins from purses**	14.50 (3.67)	23.70 (9.79)	69.54 (66.55)
4	Lift wooden cubes over edge 5cm in height**	4.13 (1.01)	4.90 (0.84)	23.47 (28.04)
5	Lift iron over edge 5cm in height**	3.43 (0.94)	3.93 (0.78)	20.67 (34.58)
6	Turning screw with screwdriver**	7.47 (1.85)	9.57 (2.46)	33.92 (41.48)
7	Pick up nuts and screw on bolts**	22.87 (6.36)	33.10 (12.91)	49.58 (53.12)
8	Put key into lock, turn 90 degrees**	4.87 (1.14)	7.27 (1.84)	53.28 (37.51)
9	Turn door-handle 30º*	2.73 (0.58)	3.07 (0.69)	15.28 (30.96)
10	Unscrew lid of jars**	6.80 (1.61)	8.27 (2.12)	24.41 (28.70)
11	Do up buttons**	15.13 (4.0)	22.50 (6.13)	53.94 (45.13)
12	Put on tubigrip stocking on the other hand**	8.03 (2.16)	12.67 (4.21)	65.54 (63.09)
13	Cut play dough with knife and fork	10.47 (3.42)	11.33 (3.00)	13.22 (26.68)
14	Write with a pen**	5.40 (1.10)	6.47 (1.31)	21.18 (17.90)
15	Fold sheet of paper and put into envelope**	16.63 (4.33)	22.33 (4.37)	40.42 (35.80)
16	Put a paper-clip on an envelope**	5.33 (1.32)	7.57 (1.99)	50.10 (52.14)
17	Lift telephone receiver, put to ear**	2.00 (0.37)	2.63 (0.81)	37.22 (53.19)
18	Pour water from carton**	19.83 (2.39)	21.23 (3.05)	7.19 (9.66)
19	Pour water from jug*	7.40 (2.14)	7.97 (1.90)	11.11 (23.53)
20	Pour water from cup	6.00 (1.51)	6.43 (1.30)	10.92 (24.42)

Figure 3 shows an overview of the percentage of score reduction observed for BBT, PPT and SHFT (Table 1), along with the mean percentage of reduction of scores of SHFT tasks (Table 2) and the mean percentage of increase in time of accomplishment of SHFT tasks (Table 3).

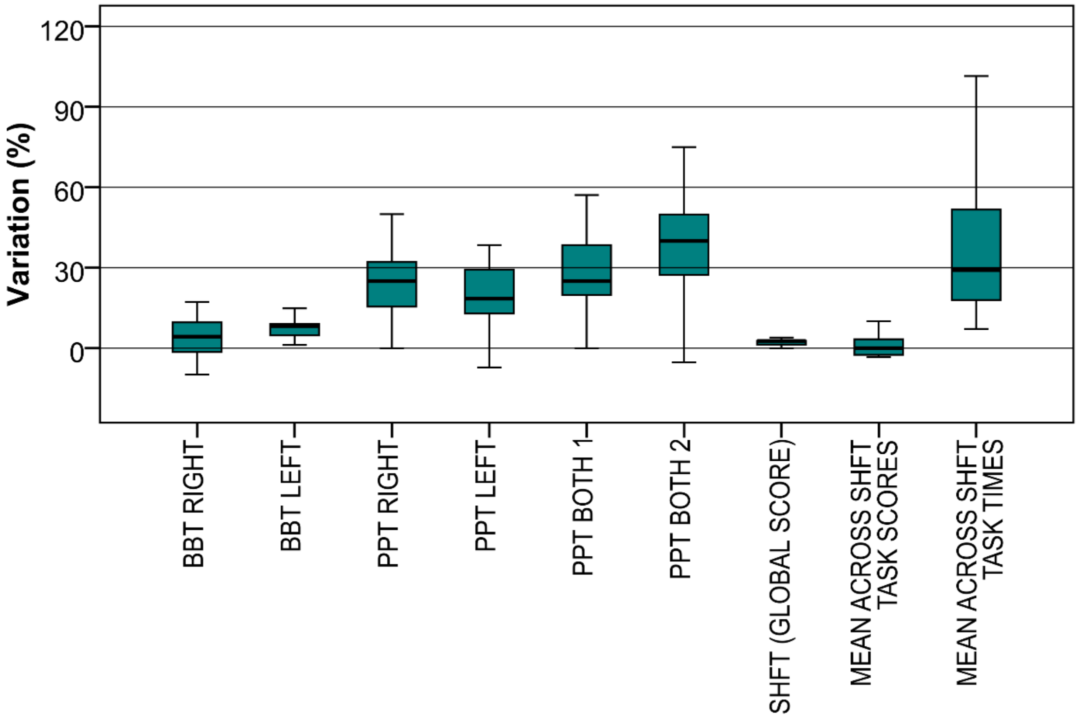

Figure 3: Changes in scores and mean time.

4. DISCUSSION

In accordance with previous works (Bishu et al., 1993; Dianat et al., 2010; Johnson and Sleeper, 1986; Muralidhar et al., 1999; Nelson and Mital, 1995; Torrens and Newman, 2000), the scores when using gloves showed a reduction in motor skills and manipulation capabilities at different levels of precision. This reduction has been previously reported to depend on certain glove characteristics like glove material and thickness (Banks, 1979; Bensel, 1993; Muralidhar et al., 1999; Plummer et al., 1985). Furthermore, wearing a glove implies a change in frictional conditions which, depending on the glove's material, affects manipulation to different extents (Bronkema-Orr and Bishu, 1996; Westling and Johansson, 1984). With the CyberGlove model with 18 DoF, which has uncovered fingertips, the protective inner glove is worn (as indicated by the glove manufacturer), which reduces touch sensitivity. For this glove model, cutting the finger ends of the inner glove to uncover fingertips may help increase touch sensitivity and, therefore, dexterity.

Fine motor skills, evaluated through the PPT, are highly affected by the use of instrumented gloves, as shown by a reduction in the scores by 29% (mean reduction of the four parts of the test). The highest reductions were found in the parts of the PPT that required the use of both hands simultaneously, i.e. the ones involving the finest motor skills. The stronger effect on dexterity reported while performing precision tasks using both hands can be attributed to reduced somatosensory feedback in both hands simultaneously, which is highly related to touch of sensitivity which, in turn, diminishes while wearing gloves (Dianat et al., 2010). Such reduced feedback may affect manipulation (Hermsdörfer et al., 2004) and, therefore, dexterity.

Gross motor skills, assessed by means of the BBT, are less affected, with a decrease of about 7.8%. The overall capability to perform ADL, when assessed through the standardised score of the SHFT, is only affected by a reduction of 2.7%. The difference in the individual scores for each task varies from a reduction of 16.67% to an increase of 10%, which is statistically significant only in the four tasks that involve the finest motor skills (picking up coins, screwing nuts, buttoning and unbuttoning, and folding paper and putting it into an envelope) where the score decreases.

However, the standardised score for the SHFT is quite rough, and especially the individual scores, which only consider a five-level score and the time of accomplishment of the tasks is considered in wide ranges (<20s, <40s, <60s, >60s). Furthermore, the grasp classification score may be somewhat subjective, as it depends on the operator. Nevertheless, when considering the exact times of accomplishment, increases from 7% to more than 100% were found, most of them statistically significant, even though no important reductions were found in the SHFT scores. The SHFT contemplates a large number of representative tasks and grasps (in comparison to BBT and PPT), but it was designed to evaluate patients with an important reduction in mobility (e.g. after an ictus). Hence despite its validity having been proved with patients with chronic stroke (Brogårdh et al., 2007) or burned hands (Weng et al., 2010) to measure hand function, it is not accurate enough to measure the effects of wearing gloves.

With regard to the effects on hand kinematics, the only information that can be extracted from BBT and PPT is that the decrease in scores reported implies a lower velocity of performance, and therefore lower hand joint velocity can be expected. The same occurs with the times of accomplishment reported in SHFT. Nevertheless, the stiffness of the glove may be affecting the range of motion and, consequently, hand kinematics. We can therefore observe that kinematic parameters (i.e. velocities and postures) may be affected when wearing instrumented gloves. Thus, data obtained using other motion capture systems that do not affect motor skills (e.g. optical systems) should not be compared with those obtained using instrumented gloves, in order to avoid bias.

A possible bias in studies that have used data gloves can be discussed from the results obtained herein depending on the recorded tasks and the reported parameters. Applications that have used the glove to record grasping static postures to validate other motion data systems (El-Sawah et al., 2007; Glauser et al., 2019) or simulation (Nogueira et al., 2019; Sancho-Bru et al., 2014) would not be affected by reported loss of dexterity, although the analysed postures may slightly differ from those used in bare-handed conditions (O’Hara, 1989). Similarly, applications that have recorded free movements for purposes such as identifying the intended type of grasp or movement performed (Naik et al., 2014; Schreck et al., 2018; Stival et al., 2019) would not be significantly affected by loss of dexterity, although glove stiffness may require slightly higher muscle activity to perform the movements. On the contrary, applications in high precision tasks, such as assessing manual dexterity in simulation-based surgery (Itkowitz et al., 2018; Lemos et al., 2017), would be clearly affected. Therefore, existing gloves should be improved for such purposes. In addition, the studies that have analysed joint velocities and/or accelerations (Jarque-Bou et al., 2018; Lin et al., 2019; Sarawate et al., 2015) may report lower velocities than real ones as the time required to perform a task would be longer than for doing it bare-handed. The joint velocity bias is expected to be higher for those tasks requiring more precision. Nevertheless, dexterity may also be affected when recording hand posture by other motion capture systems (e.g. markers of optical motion capture systems that may collide during manipulation), and this effect has not yet been studied as far as the authors know.

Even though, despite all the advantages that instrumented gloves offer regarding other motion capture systems, it is not the most suitable motion capture system when performing tasks requiring fine motor skills (as the laparoscopy one in Sánchez-Margallo et al., 2014), but are appropriate for gross motor skills and activities of daily living (as in Gracia-Ibáñez et al., 2017). However, users should take into account that kinematic parameters such as velocities should not be compared with those obtained using other systems.

5. CONCLUSIONS

The use of instrumented gloves to record hand kinematics is only recommended when performing tasks requiring medium and gross motor skills. Care has to be taken when comparing velocities with those obtained using other systems.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest for publishing this work.

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