Dear Professor Koelewijn,

We sincerely thank you and the reviewers for your time and consideration. The comments significantly helped improving the quality of our newly re-submitted manuscript. Below, in red font, please find our point-by-point answers to the reviewer's comment (localisation of the modifications in the attached manuscript and supplementals are highlighted by bold fonts). We also highlighted the modifications using red fonts in the attached manuscript and supplementals.

On behalf of all authors,

Denis Barbusse

Reviewer 1

Summary:

Authors conducted an experiment in which they assessed repetitive discrete upward and downward movements of the arm at the shoulder joint in 35 s bouts. They alternated upright and inverted positions which required about +/- 18 degree range of motion about a horizontally oriented arm and asked participants to complete as many movements as possible. Results revealed an initial difference in the first block for each body position such that relative time to peak velocity and deceleration differed for inverted condition yet people adapted to achieve similar values by the third block to suggest evidence for use of feedback and not feedforward control mechanisms. I applaud the authors for their efforts in the research. I found the study interesting and believe it will be of interest to researchers who explore gravitational influences on movement control and beyond. I do believe that authors could clarify several items for potential future readers and expand discussion on the applications of their work.

We sincerely thank the reviewer for her/his positive evaluation of our work.

General comments:

It would be great to see raw data of the movements, get insight into how many movements each person achieved in each 35 s bouts? Did the number of movements stay the same across bouts? Did it differ for upright vs inverted?

Lines 182-189 and Supplementary Table S4-5: Data and statistical analyses on number of movements per block were added in the main article and in supplementals. This addition has led to a further development in our discussion, see **lines 309-314**.

Lines 136-7: I have questions about movement accuracy. What does accuracy mean here? Having people perform movements about the horizontal places torques at

the shoulder throughout the 35 s trial which I agree will be same if people above and below the horizontal equally (line 141). However, when performing goal-directed movements with the use of vision, people have a tendency to align the position of their finger along the line of sight or gaze direction. This would result in people making greater movement excursions during movements toward the head/eyes and smaller excursions toward the feet. Authors should address the movement excursions/amplitude relative to horizontal, rather than just full amplitude, and provide insight into the implications of gaze direction and the outcomes of their study. If the people did perform equal movements above and below the horizontal, does this suggest that people ignored the allocentric visual cues for endpoint accuracy when performing the task? If they ignored the visual cues what application does this have for upright and inverted RtPA, rtPV, rtPD? What implications do either of these have on motor control?

Lines 314-319, Supplementary Figure S3 and Table S11: Here we meant that participants were not instructed to put a strong emphasis on movement accuracy. Targets simply indicated movement direction and participants had to point towards them without correcting for terminal error. Nonetheless, we performed a supplemental analysis to specifically quantify target overshoot and undershoot, and we added the results of this analysis to the supplementals (**see lines 314-319 and Supplemental Figure S3 and Table S11**, https://osf.io/pw7b4). In Head-Up body-orientation, it appears that subjects act as known with overshoot for Upward movements and undershoot for Downward movements. However, this is not the case in Head-Down body-orientation. We added a dedicated section to the discussion (see **lines 314-319**).

In lines 252-256, the results seem to work for repetitive up and down discrete vertical movements. Does this mean that the gravitational pull effects on vertical movements decay with use? Do they apply multiple goal-directed 3D movements throughout space?

The results with repetitive movements (Opsomer et al., 2021) do not show that the effects of gravity reduce with repetition, they simply highlight an adaptation that is perfect and more complete. The latter leads to an optimisation of the effects of gravity in the Head-Down body-orientation. However, it does not focus on the same parameters, analysing the amplitude of the velocity peak rather than its temporal organisation, as well as the GF-LF coupling. The present study, probing the temporal organization of arm movements at different timings (times of peak acceleration, velocity and deceleration), provides new information on the type of mechanisms (feedback vs feedforward) that may subtend the re-optimization process.

In lines 267-272, what are authors using as evidence for use of feedback information? I cannot see in the data where the cutoff for feedforward vs feedback is provided the supplementary data are relative times for direct comparisons. I assume the use of 80 ms but am unsure. Did you have people achieve PA before 80 ms?

Indeed, some movements exhibited PA before 80 ms. More specifically, such movements represented 26.9% of all movements in Head-Up body-orientation and 26% in Head-Down body-orientation. Movements with PA before 100 ms represented 65.1% of movements in Head-Up body-orientation and 52.5% in Head-Down body-orientation.

Lines 287-293 and Supplementary Table S10 and Figure S2: We carried out an analysis of the correlation between movement duration and ΔRtPA. This analysis shows that there is no correlation between these two parameters regardless of block and body-orientation. This tends to show that the behaviour was no different between the fastest and slowest movements (as also demonstrated by the analyses provided in Supplementary Table S8-9). Therefore, movements with a PA of less than 80ms (the quickest movements) do not seem to display directional asymmetries that are different from those of the slowest movements.

Minor comments/concerns:

I believe the word "gravity" is a noun and not an adjective, yet authors use it as the latter. Example on line 23 of abstract, "…face of various gravity level modifications…" should be, "…face of various gravitational level modifications…"

Lines 23, 25, 26, 27, 62, 67, 103, 233, 275: We thank the reviewer for this suggestion. We corrected the manuscript accordingly.

This is an editorial preference, but I do not care for the use inanimate objects doing things. Example, "…most studies varied gravity…" on line 25 of abstract and other places. I prefer people doing the task, such as "…most researchers varied gravity…" But of course, this is up to the editor.

Line 26: We thank the reviewer for this suggestion. We corrected the manuscript accordingly.

Line 254, I think "procee" should be "process".

Line 254: We thank the reviewer for spotting this error. We corrected the manuscript accordingly.

Limitations: Did any of your participants reveal obvious negative effects of inversion that you eliminated all or some of their data from analyses? It would be nice to have what your people experienced.

Lines 321-326: we indeed included 19 participants in this study but one did not finish the experiment because of nausea and severe headaches. Naturally, the results from this participant were not included in the present manuscript. All the other participants

were asked about their feelings and what they experienced. A large majority of participants indicated minor headaches during the first block.

Reviewer 2

Major:

I have only one major query; in the methods it is indicated that data from blocks 1-6 were analyzed, but it seems that a total of 9 blocks were conducted overall – does this mean that some of the data was excluded from the analyses? If so, why? Or have I missed some explanation of this in the text?

All participants performed 12 blocks, 6 in Head-Up body-orientation and 6 in Head-Down body-orientation alternatively. No block was excluded from the analyse (see Lines 136-140 and Figure 1B).

Minor:

Spacing between consecutive letters appears to be very tight, making it hard to read in some cases (e.g. the abbreviation 'CNS' looks like 'ONS'. Recommend changing this for legibility (either the font or the spaces between letters). There were similarly a number of blank pages inserted into my reviewer copy. I recommend that the authors revise these points in future submissions.

Lines 42, 43, 45, 57, 82, 93, 250: We increased spacing for CNS acronym as legibility seems good for the others. We also suppressed blank pages. We apologize for the inconvenience and thank the reviewer for her/his suggestions.

Please note that in several points here I used capitals here to identify several suggested changes – this is to clarify that it is only to allow me to identify the specific point in the text I would recommend changing – no 'shouting' is intended.

Abstract

23: Suggest "we are experts at producing A VARIETY OF movements" rather than the current form (it could be taken to mean 'we are experts at producing variable movements' when most of the time when we think of expertise, we observe low variability.

Line 19: Modification done; we thank the reviewer for this suggestion.

24: the scientific literature has shown that movement kinematics ARE rapidly adapted to new gravity conditions

Line 25: We thank the reviewer for spotting this error. We corrected the manuscript accordingly.

31: FURTHERMORE, comparing the evolution…

Line 32: We thank the reviewer for spotting this error. We corrected the manuscript accordingly.

Methods

Although I don't believe it is likely to affect the results of the present study, it is typical practice to report the gender breakdown of participants (Male/Female/Other).

Line 116: We added the gender breakdown. We thank the reviewer for this suggestion.

Figure 1: Part A seems to illustrate that participants were not in the apparatus that held their feet in position when they performed the 'upright' reaching parts. Did participants disengage from the tilt-frame when performing upright reaching actions?

Indeed, the participants were not in the apparatus for Head-Up blocks (see Figure 1A). This is because the apparatus configuration did not allow to tilt the body perfectly vertical in the upright position. Disengaging from the tilt-frame was however very easy and quick to perform (about 3 to 5 seconds).

119: 'the participant was either standing head-up or head-down". Were participants "standing" while upside down, or is it more accurate to say they were 'supported by the tilt frame?'. I ask this question as standing would imply engagement of postural muscles used to hold an upright position, while hanging upside down from the tilt frame might not engage these muscles, or engage other muscles to help maintain the position, and so could lead to subtle differences in muscle coactivation patterns in each case

Line 122: We agree with the reviewer and therefore have modified the text accordingly.

Study design section indicates that participants had a mandatory 30s break between each block. It would be good to indicate this on Figure 1 (I took the figure as showing that participants alternated between head-up and head-down reaching

without any pauses). Similarly the 90s break periods between blocks 4-5 and 8-9 could be illustrated in Figure 1 to help clarify this.

Figure 1B: We modified the Figure as requested by the reviewer. Please see new Figure 1 and its caption.

136: Typo; participants performed as MANY pointing movements as possible…

Line 141: We thank the reviewer for spotting this error. We corrected the manuscript accordingly.

Figure 2: The color lines with arrows are a nice way to show the 'head up' and 'head down' conditions, but I'd suggest also including a text label for each arrow for clarity.

As indicated in the figure caption, here the two colours indicate movement directions: Upward and Downward, both in Head-Up body-orientation (see Figure 2 and its caption).

Line 167 'carrying out repeated measure of variance analyses' – suggest including the abbreviation ANOVA to also clarify this was the test being used.

Line 175: We thank the reviewer for this suggestion. We corrected the manuscript accordingly.

Line 172-177: Results: Nice to start with the qualitative description of the movement times in each condition, but it would also be nice to know in the paper if there was a significant difference between them?

Line 182-189 and Supplementary Table S4-5: We added a statistical analysis on general movements characteristics in the main article and supplemental. This addition has led to a further development in our discussion, see **lines 309-314**.

Line 212: repetition of 'kinematic'.

Line 226: We thank the reviewer for this suggestion. We corrected the manuscript accordingly.

254: typo 'procee'

Line 254: We thank the reviewer for spotting this error. We corrected the manuscript accordingly.

295: 'are part of the programme of the foot hanging' – suggest replacing this with a phrase along the line of 'are reported in other studies.

Line 332: We thank the reviewer for this suggestion. We corrected the manuscript accordingly.

Reviewer 3

The authors assessed how reversing body orientation with respect to gravity (i.e., body upside down) affects the control of vertical arm movements (upward and downward) performed with a straight arm. Three main kinematic parameters were analysed, namely the relative time to peak acceleration, velocity and deceleration, and these parameters were compared between the head up and the head down position (i.e., everyday orientation vs reversed orientation relative to the gravito-inertial vector). The authors observed that for the first couple of blocks, body orientation relative to gravity significantly affected the relative time to peak velocity and deceleration. This effect vanished in the next blocks, indicating that the CNS 'required' some time and experience to optimize / re-optimize motor control taking body orientation with respect to gravity into account in order to minimize muscular effort.

The experiment is straight-forward and the results are clearly reported.

We sincerely thank the reviewer for her/his positive evaluation of our work.

My main issue / question regarding the results relates to the way the kinematic parameters were 'computed'. In particular, I was wondering whether the pattern of results would be the same would the RtP(A, V, and D)s be normalized by movement duration (for each movement and direction). Put differently, because movement amplitude was (more or less) the same for all movements, I suspect (but I might be wrong) that the relative times to peak acceleration, velocity or deceleration might be different when performing a fast vs a slower movement. For instance, I would expect the relative time to peak velocity to occur 'earlier' for faster movements (and I want to emphasize that I'm really talking about relative time and make no confusion with absolute time, for which this fact seems obvious).

RtP(A, V, and D)s are already normalized by the movement duration for each movement. For each movement, we computed RtP(A, V, and D)s as a ratio of time to peak divided by movement duration (as explained line 157-159). We computed RtP(A, V, and D)s as following for each movement, one by one :

$$RtP = \frac{Time\ to\ Peak}{Movement\ duration}$$

And after obtaining RtPs, we computed ΔRtPs as the difference of mean RtPs of upward and downward movement (ΔRtPV = RtPVdown - RtPVup) for each block of each volunteer (as explained line 157-170).

Regarding the statistical analyses, the authors mention that they assessed normality using the KS test. Why not the Shapiro-Wilk test? I'm asking that because though none of the two tests is very reliable for smaller sample sizes (say with less than 20-25 Ss), the Shapiro-Wilk test is more specific and highly recommended (because it has more power) with few data points (here only 18). Also, were the normality tests run on the residuals (this is not specified in the manuscript)?

Rechecking the normalities with the Shapiro-Wilk test revealed that normality was not confirmed for 9 out of 36 variables. However, since all the normalities were verified with KS tests and a qualitative observation of the data did not reveal any aberrant distributions, we preferred to rely on these results in order to carry out parametric tests, the results of which are more robust.

We also base our decision to use ANOVAs, on a set of articles that have shown their strong capacity for resilience and robustness with data that do not follow a normal distribution (Schmider et al., 2010, DOI : 10.1027/1614-2241/a000016; for review, see : Glass et al., 1972, DOI : 10.2307/1169991; Harwell et al., 1992, DOI : 10.2307/1165127). Finally, we would like to draw attention to the fact that the statistical tests carried out here have only been used to objectify phenomena that are already clearly visible in figures, simply by looking at the graphs in Figure 3. We were not looking for particularly low significance effects.

Overall, we strongly believe that the conclusions reached in the present manuscript would remain the same with others types of statistics.

Still regarding statistics, if I'm not mistaken, the Tukey HSD is not the most appropriate 'post-hoc' test for repeated measures, as one of the underlying assumptions is the independence of measures between conditions (groups on which means are computed).

Line 176: We thank the reviewer for spotting this mistake. We fixed this error by redoing post-hoc analyses using the Bonferroni correction. The results we obtained are only marginally different from those we first reported in the previous version of the manuscript. Comparisons that were significant under Tukey HSD are still significant under Bonferroni and no additional significance was found.

There are still some typos in the manuscript. For instance:

line 136 '… participants performed as MANY pointing movements as possible…

Line 141: Modification done. Thank you for spotting this mistake.

line 193 'As shown by a ONE-SAMPLE T-test…'

Line 206: We thank the reviewer for spotting this mistake. We corrected the manuscript accordingly.