# Soft-Constraints to Reduce Legacy and Performance Bias to Elicit Whole-body Gestures with Low Arm Fatigue

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## ABSTRACT
Participant biases can influence proposed gestures in elicitation studies. There is a *legacy bias* from previous experience with, or even knowledge of, existing input devices, interfaces, and technologies. There is also a *performance bias*, where the artificial study setting does not encourage consideration of long-term aspects such as fatigue. These biases make it especially difficult to uncover gestures appropriate for whole-body gestural input. We propose using soft constraints to correct for legacy and performance biases by penalizing physical movements. We use wrist weights as a soft constraint to elicit whole-body gestures with low arm fatigue. We show soft constraints encourage a wider range of gestures using subtler arm movements or alternate body parts and lower consumed endurance for arm movements.

### Author Keywords
Elicitation studies, whole-body gestures

### ACM Classification Keywords
H.5.m. Info. interfaces and presentation (e.g., HCI): Misc.

## INTRODUCTION
Gesture elicitation studies have become a widely used tool to inform the design of gesture sets. In a gestural elicitation study, participants are shown a system action (the "referent") and asked to propose a gesture to trigger it (the "symbol"). If suitable agreement is found among participants, a consensus gesture set may be defined [8]. In practice few gestures may have high agreement, but elicited gestures are useful to inform design [6,8]. An advantage of these studies is they should not be confined to current technologies. The focus is on user desires, not limitations of recognition technology or previous design decisions [4]. Researchers have shown that user-proposed gestures are easier to perform [5], easier to learn and recall [7], and more suitable than designer-created gestures [5]. These advantages have led to elicitation studies for technologies including touchscreens [8], mobile devices [6], and multimodal systems [3].


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Despite the benefits of elicitation studies, Morris et al. [4] argue *legacy bias* is a potential problem with elicitation studies. This is when prior experience with interfaces and technologies make it hard to uncover new gestures for an emerging medium. In previous work, participants have proposed touch gestures resembling legacy mouse input [8]. For whole-body gestures (performed by moving any part of the body without a device), we extend the definition of legacy bias beyond direct experience. We include secondhand knowledge of current body tracking capabilities and gestures portrayed in popular culture such as gaming system advertisements or science fiction films.

With this extended definition of legacy bias, we argue elicited whole-body gestures may have more to do with what is easy to track with current sensing technologies or more expressive for the sake of cinematic performance. For example, we found that for map panning, participants often mimic a gesture popularized by the Microsoft Kinect and the film *Minority Report*: they raise their arm to chest level and move it left and right (e.g. Figure 2a). Frequent use of large arm gestures like this can cause "gorilla arm" fatigue [2]. Alternative gestures using other body parts or more subtle arm movements may be more appropriate.

We believe legacy bias is compounded by what we call *performance bias*. This is when the artificial, time-limited study setting biases participants against considering long-term performance. It is difficult to get participants to consider aspects such as fatigue when their primary goal is to complete the study quickly and receive remuneration.

Morris et al. [4] proposed three techniques to overcome legacy bias: producing multiple gestures per action; priming to think about system capabilities; and running group studies. In a mid-air gesture elicitation pilot, they found that producing multiple gestures and priming resulted in a wider variety of gestures that took advantage of depth sensor capabilities. However, producing multiple gestures takes time, group studies are difficult to coordinate, and in pilot studies, we found priming with information to encourage consideration of long-term fatigue was unsuccessful.

We propose imposing *soft constraints* to reduce legacy and performance biases in gesture elicitation studies. We define a soft constraint as something that physically penalizes or encourages certain types of movement (in contrast to a *hard constraint* to prevent movement, such as wearing a straight jacket). In our study, we use wrist weights to penalize large arm movements and our results demonstrate that this soft constraint can counteract legacy and performance bias to elicit more alternative gestures with lower arm fatigue.

## STUDY

Our study uses a typical elicitation study protocol [6,8] where each participant is asked to propose gestures for common interaction tasks. The difference is that each participant proposes gestures under two conditions: a *control* condition with no constraints and a *constraint* condition in which weights were fastened around the wrists. We chose wrist weights as a soft constraint for two reasons: first, current whole-body gestures tend to use tiring large arm movements; second, the *Consumed Endurance (CE)* metric enables us to quantify a reduction in arm fatigue [2]. To provide participants time to adjust to the soft constraint, we repeat elicitation with the *constraint* condition twice.

We had three primary hypotheses:

H1. The wrist weight soft constraint will decrease the likelihood of participants proposing legacy gestures used in commercial systems (e.g. Microsoft Xbox).

H2. The wrist weight soft constraint will encourage gestures with lower *Consumed Endurance (CE)* [2].

H3. The second time gestures are elicited with the wrist weight soft constraint, they will have lower CE and fewer legacy gestures.

### Participants

Fourteen volunteers (7 female) were recruited between the ages of 21-34 ($\mu$ = 25, $\sigma$ = 3.3). All received $10 remuneration. Note that we did not control recruitment for people with and without gestural system experience since our definition of legacy bias includes indirect exposure.

### Apparatus

Images portraying action referents were ordered and displayed with custom C# software and projected on a wall. Participants stood approximately 3m from the wall and their movements were logged as time-stamped skeleton segment positions using the Microsoft Kinect SDK and depth camera (v1). Audio and video was recorded for all sessions.

### Task

For each action referent, participants were asked to propose a whole-body gesture that matched well and was "easy to perform" (fatigue is a key part of the latter). Participants were told to choose any stationary body movement that could be recognized by a person 3m away. We explicitly said the system was not an eye tracker. The 18 action referents are listed in Table 1 classified by interaction category (navigation-based actions and command actions) and usage context (a map application and interacting with tiled widgets). All actions were shown as simulated screen captures (a map or a grid of pictures) with overlaid arrows or words to convey the action. A description of each action was read aloud by the experimenter and participants were asked to design a gesture while "thinking aloud" so their thought process could be recorded. Once a gesture was chosen, they performed it 4 times while body movement was recorded.

| Category | Context | Action Referent |
|---|---|---|
| Navigation | Map Application | Move Cursor |
| | | Pan Left/Right |
| | | Pan Up/Down |
| | | Zoom In |
| | | Zoom out |
| | Tiled Widgets | Cursor Left/Right |
| | | Cursor Up/Down |
| Command | Map Application | Cancel |
| | | Confirm |
| | | Help |
| | | Select |
| | Tiled Widgets | Delete |
| | | Drag Left/Right |
| | | Drag Up/Down |
| | | Release Object |
| | | Select |
| | | Undo |
| | | View Details |

**Table 1. Referent system actions used to elicit gestures (grouped by interaction category and application context).**

### Design and Procedure

Participants proposed gestures in 3 blocks, where all 18 action referents where seen in each block. The order of usage context (map and tiled widgets) in each block was counterbalanced across participants. Block 1 was the CONTROL condition without any wrist weights. In blocks 2 and 3 the wrist weights were worn. This deterministic condition ordering is used because soft constraints produce a strong carryover effect for subsequent non-constrained conditions. The second constraint block allowed participants to refine or change their gesture given the longer exposure to the weights. These two condition-block combinations are referred to as CONSTRAINT and CONSTRAIN-FINAL. When weights were added in block 2, we found some additional explanation was necessary so participants did not think it was as an endurance test. We simply asked them to "not muscle through" since the weights are heavy. With 14 participants each performing 3 condition blocks of 18 action referents, we collected 756 gestures (with each gesture performed 4 times). Each study session lasted about one hour.

### Data Analysis and Coding

Two people coded gestures independently using synchronized audio, video, and Kinect skeleton data. This classified body part(s) used and their motion characteristics (e.g. whole arm, head nod, foot tap, etc.). Given the objective data and the think-aloud description audio, coding disagreements did not exist. Coded gestures were further examined for *legacy gestures*. A legacy gesture was designed as gestures resembling touch pinch-to-zoom, touch tapping, or a gesture used in the Microsoft Xbox with Kinect user guide. To quantify arm fatigue, we calculated Consumed Endurance *(CE)* [2] for both arms for each gesture performance using the CE Workbench [1] and our skeleton logs.

## RESULTS

### *Whole Arm and Legacy Gestures*

Out of 252 proposed gestures in the CONTROL condition, 196 (78%) used whole arm movements and 156 (62%) were identified as legacy gestures. As expected, the CONTROL condition exhibits a strong legacy bias. Further examination found that 108 of the 156 legacy gestures were proposed for the navigation action referents. This is not surprising given navigation actions are common on commercial gestural interfaces (e.g. Xbox). Out of 252 proposed gestures in the CONSTRAINT condition, 147 (58%) used whole arm gestures and 111 legacy gestures (44%). Observations for the 252 proposed gestures in the CONSTRAINT-FINAL were similar; there were 145 whole arm gestures (57%) and 109 legacy gestures (43%). There was a significant effect for condition on the frequency of arm and non-arm gestures ($\chi^2$=21.91, $p < .001$). Pair-wise comparisons shows the CONTROL condition to have significantly higher arm gestures than the CONSTRAINT and CONSTRAINT-FINAL conditions ($\chi^2$=18.68, $p < .001$ and $\chi^2$=17.17, $p < .001$ respectively). We also observed a significant effect of condition on the frequency of legacy gestures ($\chi^2$=21.91, $p < .001$). Again, pairwise comparisons show the CONTROL condition to have a higher frequency of legacy gestures than the CONSTRAINT ($\chi^2$=15.71, $p < .001$) and CONSTRAINT-FINAL ($\chi^2$=17.15, $p < .001$) conditions. There were no observed differences in the frequency of arm movements or legacy gestures between the CONSTRAINT and CONSTRAINT-FINAL conditions ($p > .9$ in all cases). The observed differences in the frequency of arm and legacy gestures between the CONTROL and CONSTRAINT conditions supports H1.

### *Consumed Endurance (CE) of Arms*

Analysis of variance (ANOVA) showed a significant effect of action referent ($F_{17, 221}$ = 5.59, $p < .001$) and condition ($F_{2, 26}$ = 20.7, $p < .001$) on mean CE of proposed gestures. Post hoc tests using Bonferroni correction showed the CONTROL condition had higher CE than CONSTRAINT and CONSTRAINT-FINAL conditions (all $p < .001$), but no difference was found between CONSTRAINT and CONSTRAINT-FINAL. Figure 1 illustrates CE by action referent and condition for map and tile contexts. Given the high percentage of whole arm gestures in the navigation category, we examined the effect of task category on CE. ANOVA showed navigation actions have higher CE than command actions ($F_{1,13}$ = 7.02, $p < .05$). It also showed a category × condition interaction ($F_{34,26}$ = 14.0, $p < .001$). Post-hoc analysis found navigation and command categories to be significantly different for the CONTROL condition (all $p < .01$), but no significant differences were found between navigation and command categories for CONSTRAINT or CONSTRAINT-FINAL conditions. The reduction in CE when constraints were applied supports H2, but no statistical evidence supports H3.

## DISCUSSION

Our results show that by adding wrist weights as soft constraints, participants propose alternate gestures. This includes gestures other than those used in legacy systems (H1 supported) and gestures with lower arm fatigue (H2 supported). We expected the need for additional time to adjust to the wrist weights, but we did not find evidence for this (H3 not supported).

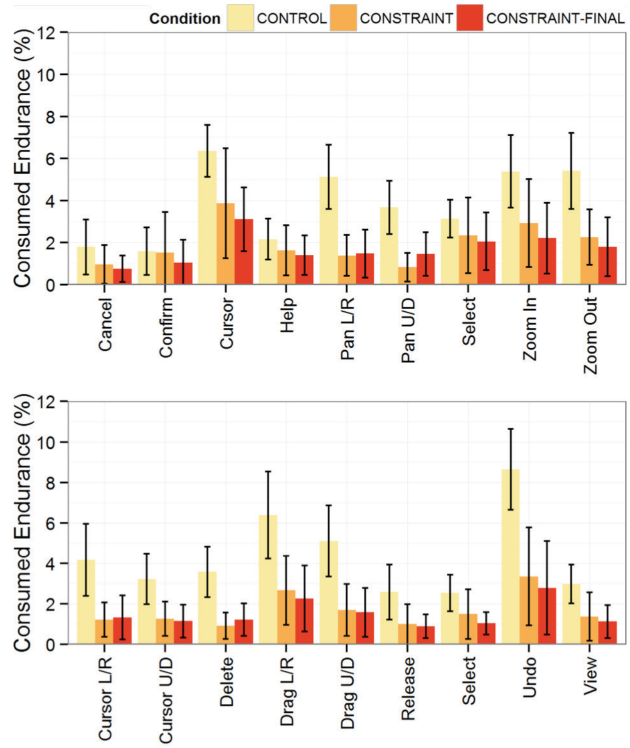


**Figure 1 Consumed Endurance for each action referent: (top) map context; (bottom) tiled widget context. SEM error bars.**

### *Limitations*

A possible limitation of soft constraints like wrist weights is that they could create a new bias favouring uncommon, less natural gestures. Like all elicitation studies, participants were instructed to propose gestures to match the task and were easy to perform. These instructions favour natural gestures, but if the only natural choice uses large arm movements, then the wrist weight soft constraints discourage it. This why we chose wrist weights and not a straightjacket – the hope is that if a large arm gesture was so compelling to use, the participant would propose it regardless of the increased wrist weight. This is why we suggest soft constraints, not hard constraints.

Perhaps due to the compelling nature of using arm gestures for some referents, participants sometimes proposed legacy gestures with higher arm fatigue even with wrist weights. This may be the soft constraints working as they should, allowing participants to selectively ignore their effect. Or, it may be that soft constraints reduce legacy and performance biases, but not completely. As future work, we plan on exploring how soft constraints can be combined with other bias reducing techniques, such as those from Morris et al. [4]

The current CE metric only applies to arms, so our study only quantifies arm fatigue. When subtler arm gestures are proposed, whole body fatigue is likely decreased. However, if proposed gestures use alternate body parts, such as using the head or foot while arms remain at the sides, whole body fatigue may decrease or increase. Future work is required to derive CE equations for these alternate body movements.

### *Elicited Gesture Characteristics and Agreement*

Agreement scores, a metric for gesture consensus among participants, can generate gesture sets [6,8]. However, abstract referents and novel device form factors lead to low scores [6]. This was the case here. Scores were low and decreased further when constraints were added. Of course, our intention is not to generate a user-defined gesture set but to test if constraints can lower arm fatigue. As discussed above, a side effect of soft constraints is a more diverse collection of gestures, which would certainly be useful to inform design. We illustrate elicited gestures for six representative referents in Figure 2. With a soft-constraint, participants minimized the use of whole arm movements, making more subtle arm motions or abandoning arm and hands and used head or foot gestures instead. Foot gestures were only suggested in the constraint conditions.

### *Other Soft Constraints*

Many other soft constraints are possible. For whole body fatigue, a body suit with elasticized tethers could dampen all movement. For low mobility gesture elicitation, participants could wear “age suits” like those worn by auto designers. Constraints could also be used to elicit context specific gestures such as walking on a treadmill to elicit walking gestures or blindfolds for eyes-free gestures.

## CONCLUSION

We introduce the use of physical soft constraints in gesture elicitation studies. An elicitation study for whole-body gestures comparing proposed gestures with and without a wrist weight constraint and found that soft constraints reduced arm fatigue by generating more diverse, non-legacy gestures using different body parts and more subtle movements. We attribute this to soft constraints counteracting our expanded definition of legacy bias and our identification of a performance bias in elicitation studies.

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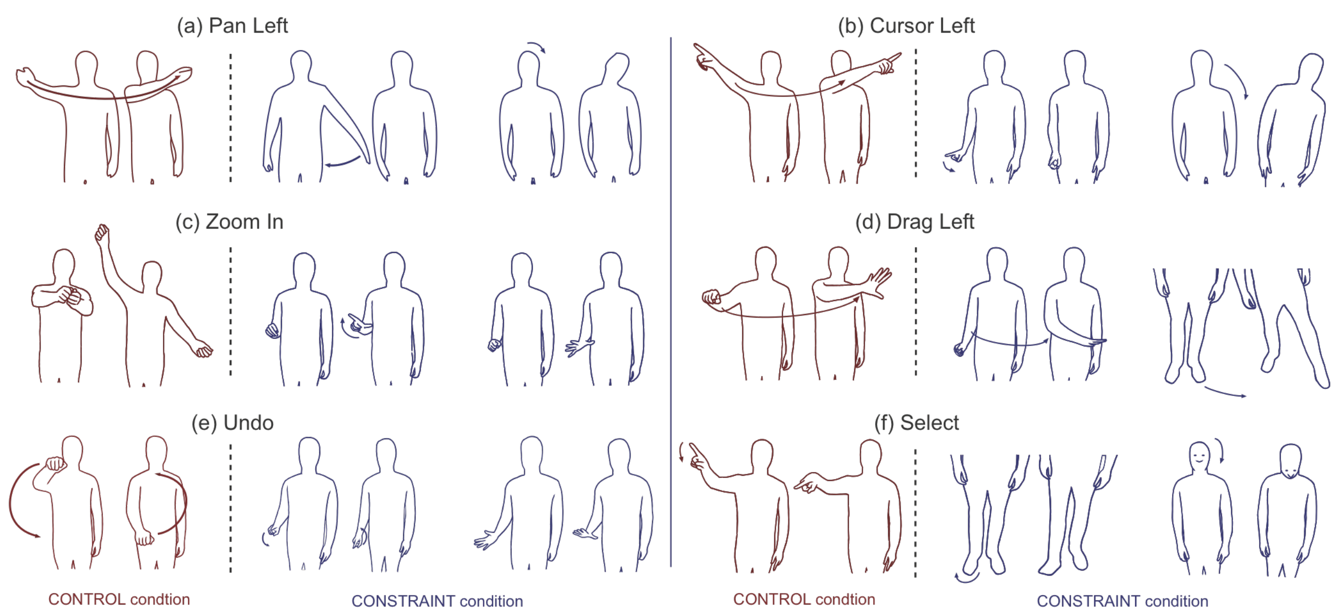


**Figure 2. Proposed gesture examples for CONTROL (no constraints) and CONSTRAINT (wrist weight soft constraints).**