Serving performance in a suprapostural visual signal detection task: context-dependent and direction-specific control of body sway with fingertip light touch

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Abstract (word count: 282)

Keeping gaze fixed on a target during visual smooth pursuit or touch light during fingertip contact while standing may resemble the goals of a suprapostural task with the implicit demands to minimize self-imposed sensorimotor variability. To test whether the principle of a suprapostural task generalizes to more complex sensorimotor stimulus-response mappings, we investigated how the control of body sway is influenced by an implicit feedback coupling (IFC) between the variability of touch forces at the contact point and perceptual difficulty, that is vertical jitter of a horizontally oscillating Landolt-C, in a visual signal detection task (VSDT). Mediolateral (ML) body sway of ten young healthy adults was assessed in four IFC conditions: (1) LT with independent jitter (LT-IJ), (2) LT with jitter depending on LT contact force (LT-CF), (3) LT with jitter depending on body sway (LT-BS), and (4) no contact with jitter depending on body sway (NT-BS). We assumed that the postural control system would be responsive to IFC and therefore reduce body sway in all IFC conditions. Resulting mediolateral body sway differed between the IFC conditions. Reduced sway was found in LT-CF and LT-BS compared to LT-IJ and in LT-BS compared to NT-BS. Our results demonstrate that processes controlling body sway can reduce postural variability below a variability level achieved by LT augmentation of body sway-related feedback alone. Both direct (LT-CF) and indirect (LT-BS) IFC involvement of fingertip contact minimized sway, which implies that no hierarchy existed for whole body sway or precision of fingertip contact (integration of both control processes) or that they can be reversed flexibly (one facilitating the other) if it serves the implicit goal of reduced perceptual noise and enhanced performance within the context of our suprapostural VSDT.

Keywords: light touch, implicit task demands, visual smooth pursuit, suprapostural task, body balance

Conflicts of interest

The authors declare that they have no conflict of interest.

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Dear Sirs,

when upright stance body sway is increased during horizontal oscillatory smooth pursuit, it may indicate interference between oculomotor and sway control, potentially due to an efferent oculomotor signal [1]. In specific contexts, however, body sway reduction has also been reported during smooth pursuit [2]. Riccio and Stoffregen [3] argued that the postural control system also takes into account an individual's behavioural goals, such as performance in a "suprapostural" task, especially when the task imposes visual demands in contrast to cognitive demands [4]. Therefore, sway may be dampened proactively to reduce self-imposed variability and to improve oculomotor accuracy during visual tracking or reduce retinal slip in a visual discrimination task [5,2,6]. Similarly, precision control of fingertip light touch (LT) with an earth-fixed reference, which most reliably reduces body sway [7], has been considered a suprapostural task [8]. The interpretation of proactive sway control assisting fingertip LT is corroborated by observations that body sway may be reduced for intermittent periods when LT is absent but nevertheless relevant to the postural context [9-11]. Is a natural sensorimotor congruency always required to elicit task-related sway adaptation or does it generalize to more complex sensorimotor stimulus-response mappings? Our present study adopted a "biofeedback" approach, in which the perceptual difficulty in a visual signal detection task (VSDT) was coupled (implicit feedback coupling, IFC) to either body sway directly or to the contact force during fingertip light touch. In both situations, we expected that body sway would be reduced proactively to ease the difficulty of the VSDT.

Ten healthy right-handed young adults (4 females, 6 males; age=26.7 yrs, SD 6.0) faced a flat-screen display (Samsung UE40D6500) in tandem stance. A force plate (600 Hz; Bertec FP4060-10) recorded body sway in terms of Centre-of-Pressure (CoP) fluctuations. A single Landolt-C was presented as the VSDT target randomly changing the direction of its opening every 2 s while continuously oscillating horizontally (0.09 Hz) across the entire width of the display. Participants were instructed to press a response button in their non-dominant hand as fast as possible when the opening of the Landolt-C pointed upwards. The dominant arm was held in a default elbow-flexed posture enabling the extended index fingertip to contact a force-torque transducer (200Hz; ATI Nano17) on a height-adjustable stand positioned in front. VSDT perceptual difficulty varied in terms of the amplitude of random vertical target jitter. Body sway was assessed in four IFC conditions: (1) LT with independent jitter (LT-IJ), (2) LT with jitter depending on LT contact force (LT-CF), (3) LT with jitter depending on body sway (LT-BS), and (4) no contact with jitter depending on body sway (NT-BS). IFC conditions were tested in randomly ordered blocks of 5 trials (120 s duration). Further details of the experimental setup are provided in the online methods supplements (Figs. 2 and 3). CoP was low-pass filtered (4th order dual-pass Butterworth with 10Hz cut-off) and differentiated to express body sway as the standard deviation of CoP velocity (dCoP). Repeated-measures ANOVA was calculated with IFC condition as within-subject factor. An alpha level of $p<0.05$ was used after Greenhouse-Geisser correction. Post-hoc single comparisons were Bonferroni-adjusted.

The proportion of hits in the VSDT task was 67% in LT-IJ, 80% in LT-CF, 77% in LT-BS and 59% in NT-BS. Average LT force was 0.85 N (SD 0.17) with no difference between the IFC conditions with LT. Resultant body sway differed between the IFC conditions ($F(3,27)=12.74$, $p<0.001$; Fig. 1). Reduced mediolateral sway was found in both LT-CF and LT-BS compared to LT-IJ (both $p<=0.007$) and in LT-BS compared to NT-BS ($p=0.003$). No difference between the IFC conditions was observed for anteroposterior sway ($p=0.12$). Nevertheless, there was a tendency for a difference between LT-BS and LT-IJ ($p=0.09$).

---------Insert Figure 1 here-----------------

Our results demonstrate a direction-specific reduction in mediolateral body sway below a level achieved by LT sway-related feedback augmentation alone if an implicit feedback coupling is present. Similar direction-specificity of sway control has been reported in visuomanual aiming [12]. In visual search involving saccadic eye movements instead of smooth pursuit, Chen et al. [13] showed that LT improved search performance. Demands of the visual search task, however, reduced sway independent of LT availability so that two processes seemed to act in parallel [13]. Similarly, in our current study, both direct (LT-CF) and indirect (LT-BS) involvement of fingertip contact in an IFC condition minimized sway, which implies either that no control hierarchy existed for whole body sway and fingertip contact (integration of both control processes) or that the hierarchy can be reversed flexibly (one facilitating the other) if it serves the implicit goal of reduced perceptual noise and enhanced performance within the context of our suprapostural VSDT.

Ethical standards

The study accorded to the ethical principles laid down in the 1964 Declaration of Helsinki and its later amendments and was approved by the Technical University of Munich Ethics Committee. All participants gave their informed consent prior to their inclusion in the study.

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Figure caption

Figure 1. (A) The experimental setup showing an individual in tandem stance on a force plate in front of the display screen with fingertip light touch of the dominant hand and a response button in the non-dominant hand. (B) Schematic of the stimulus display. A Landolt-C oscillated horizontally along a double sine-wave trajectory across the entire width of the display at a constant velocity of approximately 14°/s changing the direction of its opening every 2 s. Participants had to gaze-track the target to press the response button when its opening pointed upwards. Random jitter of variable amplitude in the vertical direction disrupted visibility of the Landolt-C opening thereby affecting the

difficulty of the visual signal detection task. Current jitter amplitude depended on the current fingertip contact force or current body sway. VA: visual angle. (C) Variability of mediolateral (ML; upper panel) and anteroposterior (AP; lower panel) body sway velocity (SD dCoP) in each implicit feedback condition (IFC). LT-IJ: fingertip light touch with independent maximum jitter amplitude; LT-CF: jitter amplitude dependent on light touch fingertip contact force; LT-BS: jitter amplitude dependent on body sway with additional fingertip light touch; NT-BS: jitter amplitude dependent on body sway without additional fingertip light touch. Error bars indicated the standard error of the mean. Straight horizontal arcs indicate significant post-hoc single comparisons ($p<0.05$), a dotted horizontal arc indicates a statistical tendency ($p<0.10$).

Supplementary Figure 2. Schematic of the processes adjusting random vertical jitter amplitude in response to light fingertip contact force or body sway in each implicit feedback condition (IFC). In each stream a reference for minimum vertical jitter amplitude was defined. In the body sway-referenced IFC condition, the average mediolateral (ML) Centre-of-Pressure position (AV ML CoP) was extracted from a pre-trial period, two seconds before the begin of the target oscillation. This resembled the baseline reference for the minimum vertical jitter amplitude. During a trial the jitter amplitude was adjusted in proportion to the deviation from the reference. In the contact force-referenced IFC condition, 1 N normal force onto the force-torque transducer resembled the baseline reference. A deviation of the contact force from this reference resulted in a proportional adjustment of jitter amplitude, if the contact force fell into the range of 0.4 N to 1.6 N. Outside this range, jitter amplitude was maximal without dependency on the contact force. In the third IFC, jitter was always maximal without any dependency on body sway or fingertip contact force. LT-IJ: fingertip light touch with independent maximum jitter amplitude; LT-CF: jitter amplitude dependent on light touch fingertip contact force; LT-BS: jitter amplitude dependent on body sway with additional fingertip light touch; NT-BS: jitter amplitude dependent on body sway without additional fingertip light touch.

Supplementary Figure 3. Data traces illustrating each of the implicit feedback coupling (IFC) conditions. The top row shows the target jitter on the display screen and the middle row the corresponding input signal generating the evoked jitter response. The bottom row shows mediolateral body sway velocity (ML dCoP). LT-IJ: fingertip light touch with independent maximum jitter amplitude; LT-CF: jitter amplitude dependent on light touch fingertip contact force; LT-BS: jitter amplitude dependent on body sway with additional fingertip light touch; NT-BS: jitter amplitude dependent on body sway without additional fingertip light touch.

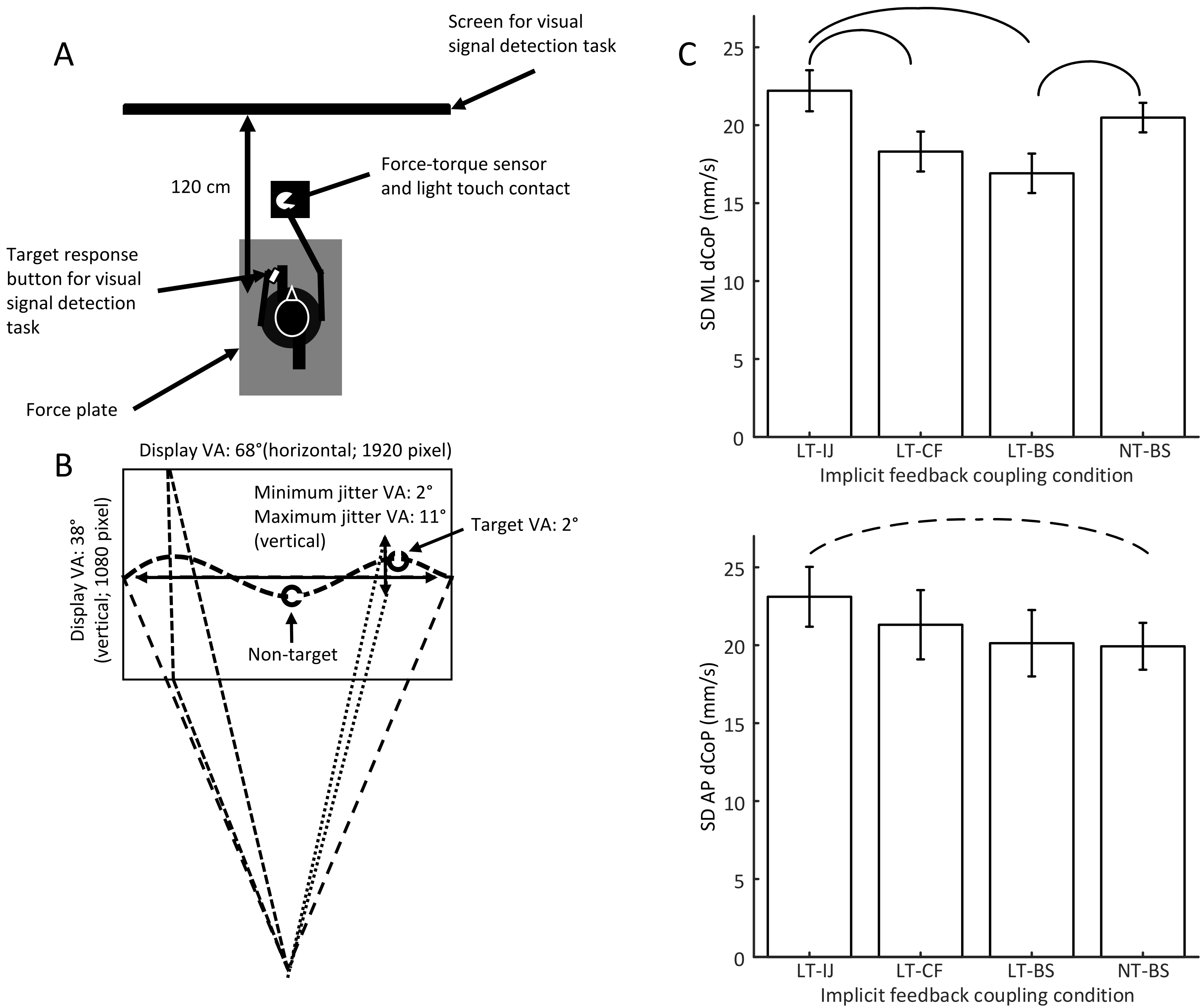
A
Screen for visual signal detection task
120 cm
Force-torque sensor and light touch contact
Target response button for visual signal detection task
Force plate
B
Display VA: 68°(horizontal; 1920 pixel)
Display VA: 38° (vertical; 1080 pixel)
Minimum jitter VA: 2°
Maximum jitter VA: 11°
(vertical)
Target VA: 2°
Non-target
C
SD ML dCoP (mm/s)
0
5
10
15
20
25
LT-IJ
LT-CF
LT-BS
NT-BS
Implicit feedback coupling condition
SD AP dCoP (mm/s)
0
5
10
15
20
25
LT-IJ
LT-CF
LT-BS
NT-BS
Implicit feedback coupling condition

Figure 1.

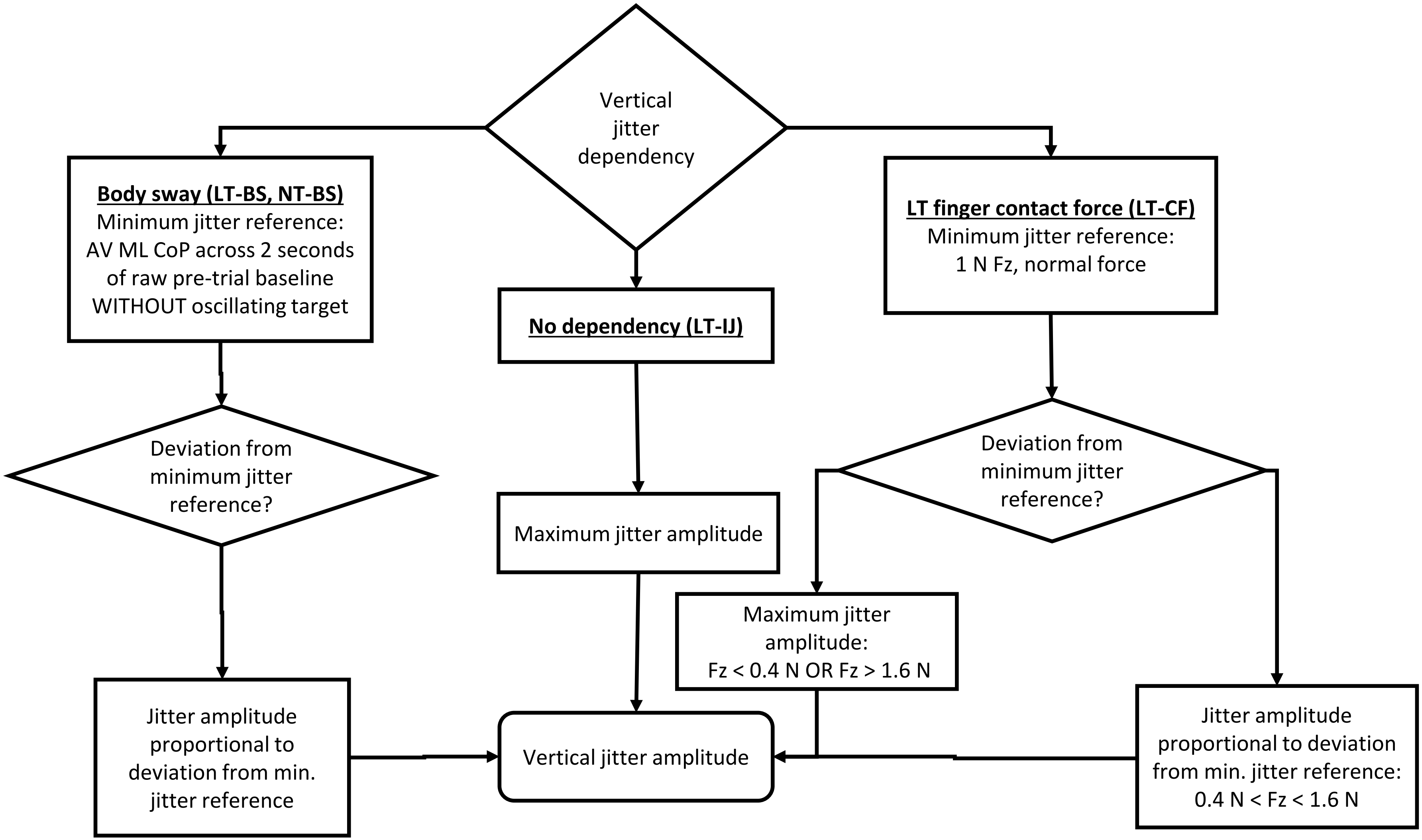
Vertical jitter dependency
Body sway (LT-BS, NT-BS)
Minimum jitter reference: AV ML CoP across 2 seconds of raw pre-trial baseline WITHOUT oscillating target
No dependency (LT-IJ)
LT finger contact force (LT-CF)
Minimum jitter reference: 1 N Fz, normal force
Deviation from minimum jitter reference?
Maximum jitter amplitude
Deviation from minimum jitter reference?
Maximum jitter amplitude: Fz < 0.4 N OR Fz > 1.6 N
Jitter amplitude proportional to deviation from min. jitter reference
Vertical jitter amplitude
Jitter amplitude proportional to deviation from min. jitter reference: 0.4 N < Fz < 1.6 N

Figure 2.

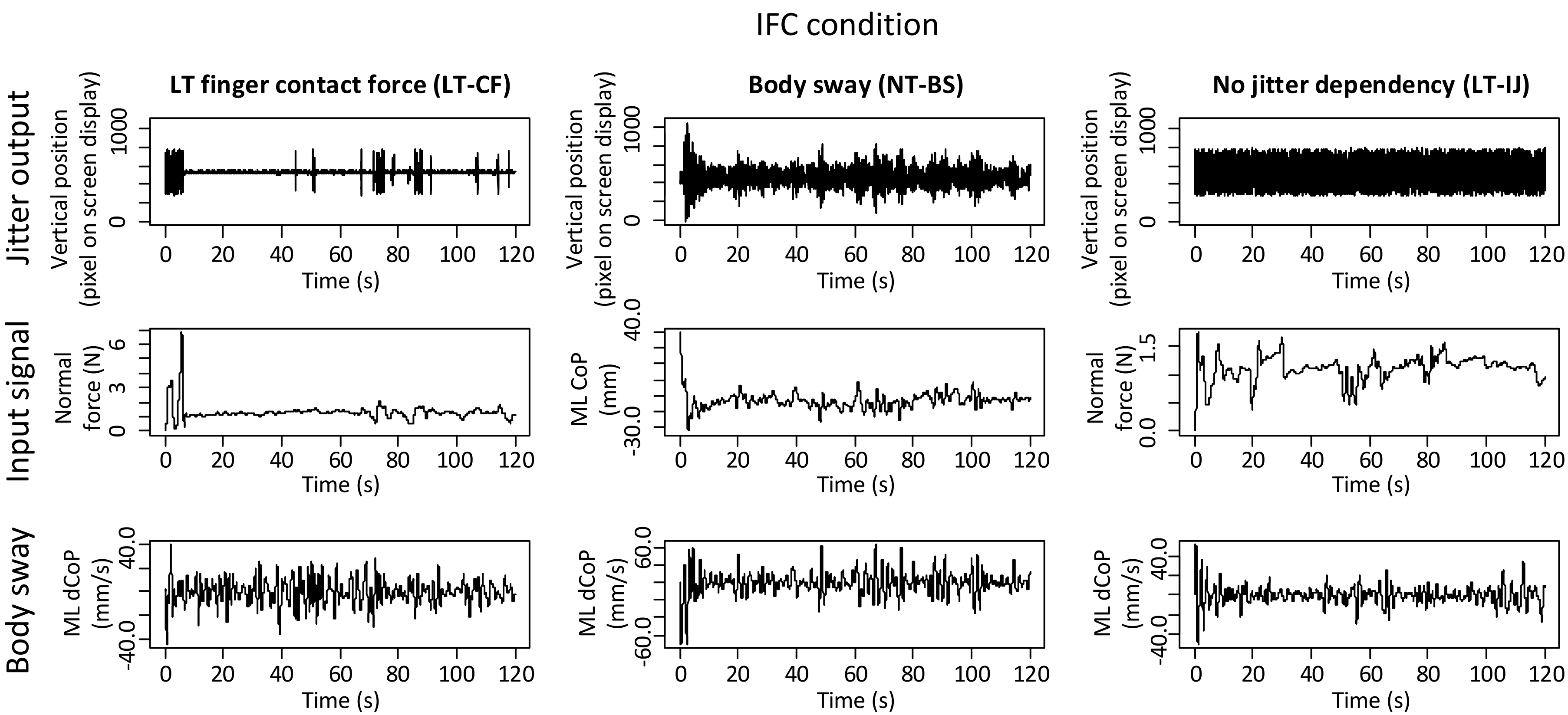
IFC condition
LT finger contact force (LT-CF)
Body sway (NT-BS)
No jitter dependency (LT-IJ)
Jitter output
Input signal
Body sway
Vertical position (pixel on screen display)
Normal force (N)
ML CoP (mm)
ML dCoP (mm/s)
Time (s)

Figure 3.