Original Article
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Medical Journal of the Islamic Republic of Iran (MJIRI)

Med J Islam Repub Iran. 2024 (27 Nov);38.138. https://doi.org/10.47176/mjiri.38.138

Effect of Light Touch and Visual Tracking on Non-Linear Features of Postural Control System

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Received: 17 Nov 2023 Published: 27 Nov 2024

Abstract

Background: Both the light touch (LT) of the fingertip on a surface and the visual tracking (VT) implementation can affect postural sway. In this study, we examined the individual effects of LT and VT performance on dynamic features of the postural control system and if LT plus VT provides an additional benefit for stance stability.

Methods: In this repeated measures design, ten young, healthy individuals (29.80 ± 3.35 years) were instructed to maintain quiet standing in 4 test conditions: No Visual Tracking No Light Touch (N), Visual Tracking only (VT), Light Touch only (LT), Visual Tacking + Light Touch (VTLT). The Repeated Measure ANOVA (2*2), the Wilcoxon test, and the Paired Student's t-test were used. The significance level was set at $P < 0.05$.

Results: The center of pressure (COP) sway decreased, and the COP Approximate Entropy (ApEn), Sample Entropy (SampEn), and Correlation Dimension increased with LT ($P \leq 0.010$). VT led to a significant decrease in COP sway ($P=0.030$) and a significant increase in COP anterior-posterior ApEn and SampEn ($P<0.001$). Compared to the N condition, changes of both linear and non-linear COP measures were greater in the VTLT condition than when LT or VT was performed individually.

Conclusion: LT during quiet stance increased both the complexity and dimensionality of the postural control system in young healthy individuals which reflected the more automatic control of posture with LT. Besides, the performance of VT increased postural control complexity. Postural control is not only better adapted to perform individual LT and VT, but also there is a further adaptation of postural control to perform both LT and VT together. Adding VT to balance exercises using LT should be explored as an effective means to improve standing stability.

Keywords: Fingertip touch, Visual pursuit, Postural stability, Supra- postural task, Complex system

Conflicts of Interest: None declared
Funding: The research reported in this paper was part of a Ph.D. thesis by Mina Mirahmadi. This project was supported by grant No 1398.847 from the Iran University of Medical Sciences.

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Cite this article as: Mirahmadi M, Jafari AH, Salehi R, Mansour Sohani S. Effect of Light Touch and Visual Tracking on Non-Linear Features of Postural Control System. *Med J Islam Repub Iran.* 2024 (27 Nov);38:138. https://doi.org/10.47176/mjiri.38.138

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[DOI: 10.47176/mjiri.38.138]

Introduction

Maintaining a finger-light touch (LT) with a force of less than 1 N on a surface reduces postural sway (1). This touch effect has been observed in both healthy individuals and those with balance disorders frequently (2) which recently has led to the use of LT in rehabilitation programs for the improvement of postural control (3). There are two hypotheses for the LT effect, the sensory hypothesis and the supra-postural task hypothesis which can coexist for adaptive postural control, and in various conditions, one is dominant over another (4).

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↑What is "already known" in this topic:
Maintaining a finger-light touch (LT) with a force of less than 1 N on a surface reduces postural sway in standing. In addition, the performance of visual tracking (VT) improves stance stability. No investigation has addressed whether there was an added benefit of concomitant VT when doing LT during shoulder width stance in young, healthy individuals.

→What this article adds:
Combining VT and the LT task provided an additional benefit for both linear and non-linear features of the postural control system during quiet stances in healthy young adults. This may lay the groundwork to help guide rehab efforts associated with balance exercises using LT.

Visual tasks like following a moving target with eyes or visual searching during a quiet stance need an efficient postural control system. A recent literature review showed that the performance of visual tracking (VT) decreases Center-Of-Pressure (COP) sway and improves stance stability in young healthy individuals (5). However, some studies reported the destabilizing effect of the visual pursuit (6, 7). A recent study indicated that a potential cause for the observed controversy in this field could lie in “foot placement” while standing (7). The research studies that placed participants with their feet together during VT, reported an increase in postural sway (6, 7). However, other studies that examined body sway during active visual tasks in standing with wide foot width all showed a reduction in sway (8, 9). Therefore, Visual Tracking during shoulder width stance could decrease postural sway. To the best of our knowledge, no previous investigation has addressed if there was an added benefit of concomitant VT when doing LT during shoulder-width stance in young, healthy individuals. Such an investigation may lay the groundwork to help guide rehab efforts associated with balance exercises using LT.

It is of note that the dominant view in the assessment of the “LT effect on postural control” and the “VT effect on postural control” is a reductionistic view. Movement in this approach is a linear behavior that is simplified into its elements, analyzed as the sum of these elements, and causality is seen in a linear way. Therefore, changes in the postural control system are evaluated by the traditional linear COP measures which represent the quantity of changes in the postural control system and consider the magnitude of COP sway not its pattern. Also, the averaging method used to quantify the classic linear variables can mask how the variability of COP fluctuations changes over time (10, 11). However, following the definition of ‘Movement System’ in agreement with the complex system approach (dynamic systems), the movement is an emergent behavior such that its ensemble properties are permitted by but not determined by its elements properties and its assessment needs appropriate non-linear measures (12) which are sensitive to the patterns in COP time series data and could represent the quality of changes in the postural control system. Indeed, the non-linear variables of COP are able to assess the temporal structure of its sway (10, 11, 13). Thus non-linear features of COP could bring a complementary understanding of postural control (7, 14). Many studies have examined the LT effect on the linear variables of postural control and showed a decrease in COP Standard Deviation, Root Mean Square, Velocity, and Path length with LT (2, 4, 15-18) but only a few studies evaluated LT effect on non-linear features of postural control and demonstrated the increase of COP Sample Entropy (SampEn) and Correlation Dimension with LT (13, 19, 20). Moreover, there is only one study that has examined the VT effect on the non-linear variables of postural control and observed an increase of COP SampEn with VT (7). In this study, we examined the effects of the individual and concomitant performance of LT and VT on COP sway using some linear measures and some non-linear ones which are defined and explained in the method section in detail.

In the current study, our aim was to investigate the effects of LT and VT on linear and non-linear features of the postural control system during shoulder-width stance in young, healthy individuals. Therefore, we focused on two main hypotheses. Firstly, we expected a reduction of COP sway with LT because of findings that LT improves quiet stance postural sway (1, 2, 21). COP ApEn, SampEn, and Correlation Dimension, however, were expected to increase with LT based on the current literature (13, 19). Secondly, we supposed that VT decreases COP sway (5, 9) and increases COP ApEn, SampEn, and Correlation (7, 22, 23). Finally, in this study, we aimed to answer this question, “is there an additional benefit of simultaneous performance of LT and VT compared to their individual performance for linear and non-linear COP measures of the quiet stance postural control in young adults?”

Methods

Participants

In this repeated measures design, ten healthy individuals were involved (29.80 ± 3.35 years, nine females), and convenience sampling was used to enroll them. All participants provided written consent before participation in the study. The participants had no previous history of neuromuscular disorder, recent physical injury or pain.

Apparatus and Task

Participants stood barefoot on a force plate (Kistler, Type 9260AA, 50*60 cm^2, Zurich, Switzerland) with their feet shoulder-width apart, maintaining a steady stance and refraining from talking for 60 seconds. Test conditions included 4 randomly performed states: 1) No Visual Tracking No Light Touch (N), 2) Visual Tracking only (VT), 3) Light Touch only (LT), and 4) Visual Tracking and Light Touch (VTLT). Three trials were performed for each experimental condition. For all trials, participants were required to keep their dominant elbow flexed approximately at 90 °, pronate their forearm, maintain their wrist in the neutral position, make a light fist then extend only their index finger, and the non-dominant arm was to be hung along their side. In conditions 1 and 3, participants were instructed to maintain their gaze on an ‘’X’’ target printed in 72-point Times New Roman bold font (at approximately eye-level) on a white background which was affixed 1.5 m away. In conditions 2 and 4, participants were asked to follow the visual target with their eyes so that they were always looking at the target’s current location and the visual target consisted of a moving filled black circle (diameter: 2.5 cm) on a very light pink background (screen size: 14’’) located 1.5 m away from the participant (Figure 1). The touched surface was a cloth curtain (30*30 cm^2) that was hung on a tripod (height: 130 cm) placed in front of the participant (Figure 1). In conditions 1 and 2, it was located far from the participant's finger not to be touched during the test. In conditions 3 and 4, the cloth curtain was touched with the fingertip of the participant's index finger. Before data collection, participants practiced all conditions for task familiarization. A 60 s resting period between trials was provided. The duration of the entire experiment was approximately 25-30 min. The sampling rate of 100 Hz was

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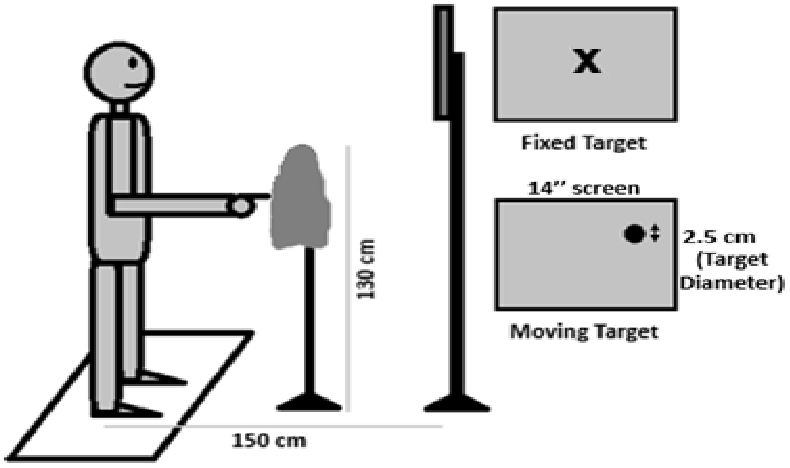

Figure 1. Schematic of the experimental setup and participant position during tests

used, and a Butterworth low pass filter with a cutoff frequency of 10 Hz was applied (24).

Data Analysis
Linear Measures

In this study, linear measures of COP sway (including range, Standard Deviation of amplitude, and Root Mean Square) in Anterior-Posterior (AP) and Medial-Lateral (ML) directions were used which were calculated as below (25):

1. RangeAP (mm) = x_{max} - x_{min}
2. RangeML(mm) = y_{max} - y_{min}
3. SDAP(mm) = $\sqrt{\frac{\sum(x_i-\bar{x})^2}{n-1}}$
4. SDML(mm) = $\sqrt{\frac{\sum(y_i-\bar{y})^2}{n-1}}$
5. RMSAP(mm) = $\sqrt{\frac{\sum {x_i}^2}{n}}$
6. RMSML(mm)= $\sqrt{\frac{\sum {y_i}^2}{n}}$

Non-linear Measures

In this study, non-linear measures of COP sway, including Correlation Dimension, Approximate Entropy, and Sample Entropy in AP and ML directions, were examined. These measures will be explained in three parts as follows.

Correlation Dimension

Correlation Dimension is the variable to measure the dimensionality of the postural control system. The dimension is the number of independent variables or equations of motion that are needed to reproduce the temporal evolutionary characteristics of the COP time series data (26). The procedure for calculating the Correlation Dimension is as follows:

The COP (n) is modeled in a m-dimensional Euclidean space as

$X_m(n) = [x(n), x\ (n-\lambda), \dots, x(n-(m-1)\lambda)]$

In the above equation, $x(n)$ is the COP time series, λ is the time delay, and m is the embedding dimension.

The correlation Dimension is calculated as:

$CD = \lim_{r\to 0} \frac{\log C(r)}{\log\ (r)}$, where C (r) $= \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1,i\neq j}^{N}\theta(r-|v_i-v_j|)$

C (r) is the correlation integral, the mean probability that the states at two different times are close. N is the number of data points in phase space. r is the radial distance around each reference point x_i. v_i, v_j are points of the trajectory in the phase space and θ is the Heaviside function (27).

Approximate Entropy

Approximate Entropy (ApEn) is the variable to measure the amount of complexity (irregularity or unpredictability) of fluctuations over COP time series data. Here, the ApEn was defined as ApEn (m, r, N), with m as the length of compared runs, r as tolerance, and N as input data points. The procedure for calculating ApEn is as follows (28):

Given a time-series of data, u(1), u(2),.....,u(N) from measurements form a sequence of vectors: x(1), x(2),.., x(N – m + 1) in R^m, defined by x(i) = [u(i), u(i + 1),...., u(i + m – 1)].

Define for each i, $1 \le i \le N - m + 1$:

$C_i^m(r) = \frac{number\ of\ j\ such\ that\ d[x(i),x(j)]\le r}{N-m+1}$

where:

d[x(i),x(j)] = max (|u (i + k – 1) – u (j + k – 1)|),..... k = 1,2,...,m

Define: $\Phi^m(r) = \frac{1}{N-m+1}\sum_{i=1}^{N-m+1}\log {C_i}^m(r)$

Then:

$ApEp(m,r,N) = \Phi^m(r) - \Phi^{m+1}(r)$

Sample Entropy

Sample Entropy (SampEn) is another measure used to assess the complexity of COP data. This variable does not include self-matches. Therefore, its use eliminates the ApEn bias (the bias towards regularity). Here, the sample entropy was defined as SampEn (m, r, N), the negative natural logarithm of the conditional probability that a dataset of length N, having repeated itself for m samples within a tolerance r, will also repeat itself for m + 1 samples, without allowing self-matches. The procedure for calculating SampEn is as

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follows (29):

Given a standardized time series x_1, x_2, ..., x_N, the first step of the algorithm is to define subsequences (also called template vectors) of length m given by yi (m) = (x_i , x_{i+1} ,..., x_{i+m-1}) with i = 1, 2,..., N − m + 1. Then, the following quantity is defined:

$$B_i{}^m(r) = \frac{1}{N-m-1} \sum_{j=1, j\neq i}^{N-m} \theta(r - \|yj\ (m) - yi\ (m)\|\infty)$$

where θ is the Heaviside function, ‖ . ‖∞ is the maximum norm defined by $\|yj\ (m) - yi\ (m)\|\infty) = \max_{0\leq k\leq m-1}$ |xj+k − xi+k |. The sum simply represents the number of vectors yj (m) that are within a distance (or a radius) r from yi (m) in the reconstructed phase space. In this formula, the cases for which j = i are excluded to avoid counting the so-called "self matches". The next step of the process is to calculate the density:

$$B^m(r) = \frac{1}{N-m} \sum_{i=1}^{N-m} B_i{}^m(r)$$

Similar computations are then performed in a (m + 1)-dimensional reconstructed state space.

$$A_i{}^m(r) = \frac{1}{N-m-1} \sum_{j=1, j\neq i}^{N-m} \theta(r - \|yj\ (m+1) - yi\ (m+1)\|\infty)$$

$$A^m(r) = \frac{1}{N-m} \sum_{i=1}^{N-m} A_i{}^m(r)$$

Two last quantities are calculated.

B(r) = 1/ 2 (N − m − 1)(N − m)B ^{m}(r)

A(r) = 1/ 2 (N − m − 1)(N − m)A ^{m}(r)

B(r) and A(r) are defined as being the total number of template matches in a m-dimensional (resp. (m + 1)-dimensional) phase space within a tolerance r. The densities B ^{m}(r) and A ^{m}(r) are calculated for the same number of templates (N − m, which is the number of vectors in the (m + 1)- dimensional state space). Then:

SampEn (m, r, N) = − log (A(r) /B(r))

The data were analyzed and processed with MATLAB R2018b (MathWorks, Natick, USA) software.

Statistical Analyses

The normal distribution of COP measures was examined using the Shapiro-Wilk test. The mean (SD) values of the variables that were normally distributed and the median values for those without normal distribution in the four test conditions are shown in Tables 1 and 2 for linear and non-linear measures, respectively. The parameters that did not present normal distribution were transformed to log10 before using the Repeated Measure ANOVA (2*2). This test with 2 levels for LT (No Light Touch/ Light Touch), and 2 levels for VT (No Visual Tracking/ Visual Tracking) was used to examine the first and the second hypotheses of the study. In addition, we used the Wilcoxon test and Paired Student's t-test for linear and non-linear COP measures, respectively, to answer the question of the study "Is there an additional benefit of simultaneous performance of LT and VT compared to their individual performance?". In these tests, we compared the conditions N with VT (N-VT), N with LT (N-LT), and N with VTLT (N-VTLT). Then if the

Table 1. Postural Stability Linear Measures Results, Additional Benefit of VTLT Compared to VT or LT

Test Conditions	RangeAP (mm)	RangeML (mm)	RMSAP (mm)	RMSML (mm)	SDAP (mm)	SDML (mm)
	Median (Q1, Q3)	Median (Q1, Q3)	Median (Q1, Q3)	Median (Q1, Q3)	Median (Q1, Q3)	Median (Q1, Q3)
N	20.57 (18.56, 23.77)	12.46 (7.79, 15.94)	3.85 (3.41, 4.83)	2.17 (1.25, 2.63)	3.85 (3.41, 4.83)	2.17 (1.25, 2.63)
VT	19.23 (16.09, 25.43)	10.56 (6.15, 14.98)	3.45 (3.02, 4.60)	1.90 (1.02, 2.22)	3.45 (3.02, 4.60)	1.90 (1.02, 2.22)
LT	13.89 (11.67, 20.95)	8.34 (5.80, 12.62)	2.84 (2.16, 3.88)	1.55 (1.03, 2.13)	2.84 (2.16, 3.88)	1.55 (1.03, 2.13)
VTLT	13.68 (11.96, 16.11)	6.85 (5.83, 10.14)	2.39 (1.97, 3.24)	1.16 (0.88, 1.63)	2.39 (1.97, 3.24)	1.16 (0.88, 1.63)
Wilcoxon Test	RangeAP (mm) Median Difference z p	RangeML (mm) Median Difference z p	RMSAP (mm) Median Difference z p	RMSML (mm) Median Difference z p	SDAP (mm) Median Difference z p	SDML (mm) Median Difference z p
N-VT	1.34 -0.76 0.440	1.90 -1.58 0.110	0.39 -1.78 0.070	0.26 -1.58 0.110	0.39 -1.78 0.070	0.26 -1.58 0.110
N-LT	6.68 -2.59 <0.001	4.12 2.19 0.020	1.00 2.70 <0.001	0.61 1.78 0.070	1.00 2.70 <0.001	0.61 1.78 0.070
N-VTLT	6.89 6.37 <0.001	5.61 3.47 0.000	1.45 6.76 <0.001	1.00 3.68 <0.001	1.45 6.76 <0.001	1.00 3.68 <0.001

N: No Visual Tracking No Light Touch, VT: Visual Tracking only, LT: Light Touch only, and VTLT: Visual Tracking and Light Touch, RangeAP: Range of Center Of Pressure (COP) sway in Anterior/Posterior (AP) direction, RangeML: Range of COP sway in Medial/Lateral (ML) direction, RMSAP: Root Mean Square of COP sway in AP direction, RMSML: Root Mean Square of COP sway in ML direction, SDAP: Standard Deviation of COP sway in AP direction, SDML: Standard Deviation of COP sway in ML direction, Significant p values (p≤0.05) are indicated in bold.

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Table 2. Postural Stability Non-Linear Measures Results, Additional Benefit of VTLT Compared to VT or LT

Test Conditions	CDAP	CDML	ApEnAP	ApEnML	SampEnAP	SampEnML
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
N	2.55 (0.13)	2.69 (0.15)	0.09 (0.02)	0.15 (0.04)	0.08 (0.02)	0.13 (0.04)
VT	2.58 (0.13)	2.77 (0.29)	0.11 (0.02)	0.17 (0.05)	0.09 (0.02)	0.14 (0.04)
LT	2.57 (0.13)	2.82 (0.16)	0.12 (0.05)	0.18 (0.06)	0.10 (0.04)	0.16 (0.05)
VTLT	2.73 (0.42)	3.01 (0.35)	0.15 (0.06)	0.21 (0.06)	0.14 (0.05)	0.19 (0.06)
Paired Student's t-test	CDAP Mean Difference t p	CDML Mean Difference t p	ApEnAP Mean Difference t p	ApEnML Mean Difference t p	SampEnAP Mean Difference t p	SampEnML Mean Difference t p
N-VT	-0.02 -0.47 0.640	-0.08 -1.20 0.260	-0.02 -2.86 0.010	-0.01 -.1.05 0.320	-0.01 -2.31 0.040	-0.01 -1.16 0.270
N-LT	-0.02 -0.49 0.630	-0.13 -2.54 0.030	-0.02 -2.06 0.060	-0.03 -1.89 0.090	-0.02 -2.02 0.070	-0.03 -2.06 0.060
N-VTLT	-0.17 -1.55 0.150	-0.32 -3.34 <0.001	-0.06 -5.41 <0.001	-0.05 -2.79 0.020	-0.06 -4.98 <0.001	-0.05 -3.14 0.010

N: No Visual Tracking No Light Touch, VT: Visual Tracking only, LT: Light Touch only, and VTLT: Visual Tracking and Light Touch, CDAP: Correlation Dimension of Center Of Pressure (COP) sway in Anterior/Posterior (AP) direction, CDML: Correlation Dimension of COP sway in Medial/Lateral (ML) direction, ApEnAP: Approximate Entropy of COP sway in AP direction, ApEnML: Approximate Entropy of COP sway in ML direction, SampEnAP: Sample Entropy of COP sway in AP direction, SampEnML: Sample Entropy of COP sway in ML direction. t: t distribution (the degree of freedom and N values are 9 and 10, respectively.), Significant p values ($p \leq 0.05$) are indicated in bold.

COP sway reduction (or the changes of COP entropy and Correlation Dimension) were more in the N-VTLT comparison than the N-VT comparison, it was considered that there is an additional benefit of simultaneous performance of LT and VT compared to individual performance of VT. Similarly, if the COP sway reduction (or the changes of COP entropy and Correlation Dimension changes) were more in the N-VTLT comparison than the N-LT comparison, it was considered that there is an additional benefit of simultaneous performance of LT and VT compared to the individual performance of LT. The significance level was considered at $\alpha = 0.05$. The analyses of data were performed using SPSS 22.

Results

The significant results of the Repeated Measure ANOVA (2*2) are reported in the first section for linear and the second section for non-linear COP measures. There was no interaction effect between LT and VT for any of the variables investigated. The results of the Wilcoxon test and Paired Student's t-test are shown in Tables 1 and 2 for linear and non-linear variables, respectively.

Linear Measures

The main effect of LT on the COP range in both AP and ML directions reached significance (RangeAP, $F(1, 9)=21.08$, $P<0.001$, $\eta 2=0.70$; RangeML, $F(1, 9)=9.64$, $P=0.010$, $\eta 2=0.51$). COP range decreased with LT (Figure 2 a). The main effect of LT on the COP RMS in both AP and ML directions reached significance (RMSAP, $F(1, 9)=19.52$, $P<0.001$, $\eta 2=0.68$; RMSML, $F(1, 9)=10.53$, $P=0.010$, $\eta 2=0.53$). Also, the main effect of LT on the COP SD in both AP and ML directions reached significance (SDAP, $F(1, 9)=19.52$, $P=0.000$, $\eta 2=0.68$; SDML, $F(1, 9)=10.53$, $P=0.010$, $\eta 2=0.53$) and COP sway decreased with LT. The VT effect on the COP RMS and SD in the AP direction was also significant ($F(1, 9)=6.07$, $P=0.030$, $\eta 2=0.40$), and VT led to a decrease in COP sway (Figure 3).

Non-Linear Measures

The main effect of LT on the ApEn and SampEn in both AP and ML directions and Correlation Dimension in the ML direction reached significance (ApEnAP, $F(1, 9)=11.46$, $P=0.000$, $\eta 2=0.56$; ApEnML, $F(1, 9)=8.88$, $P=0.010$, $\eta 2=0.49$; SampEnAP, $F(1, 9)=10.64$, $P=0.010$, $\eta 2=0.54$; SampEnML, $F(1, 9)=9.95$, $P=0.010$, $\eta 2=0.52$; Correlation Dimension ML, $F(1, 9)=14.14$, $P=0.000$, $\eta 2=0.61$). COP Entropy and Correlation Dimension increased with LT (Figure 2 b, c). The VT effect on the COP ApEnAP and SampEnAP reached significance (ApEnAP, $F(1, 9)=17.04$, $P<0.001$, $\eta 2=0.65$; SampEnAP, $F(1, 9)=11.97$, $P<0.001$, $\eta 2=0.57$) and VT led to increasing COP Entropy (Figure 4).

Discussion

In the present study, we evaluated the LT effect and the VT effect on linear and non-linear features of the postural control system during shoulder width stance in young healthy individuals. Also, we examined whether LT plus VT provides an additional benefit for postural stability compared to the individual performance of LT. Two hypotheses were assumed in this study. The first hypothesis was confirmed as COP sway reduced and COP ApEn, SampEn, and Correlation Dimension increased with LT. The second hypothesis was supported by linear and non-

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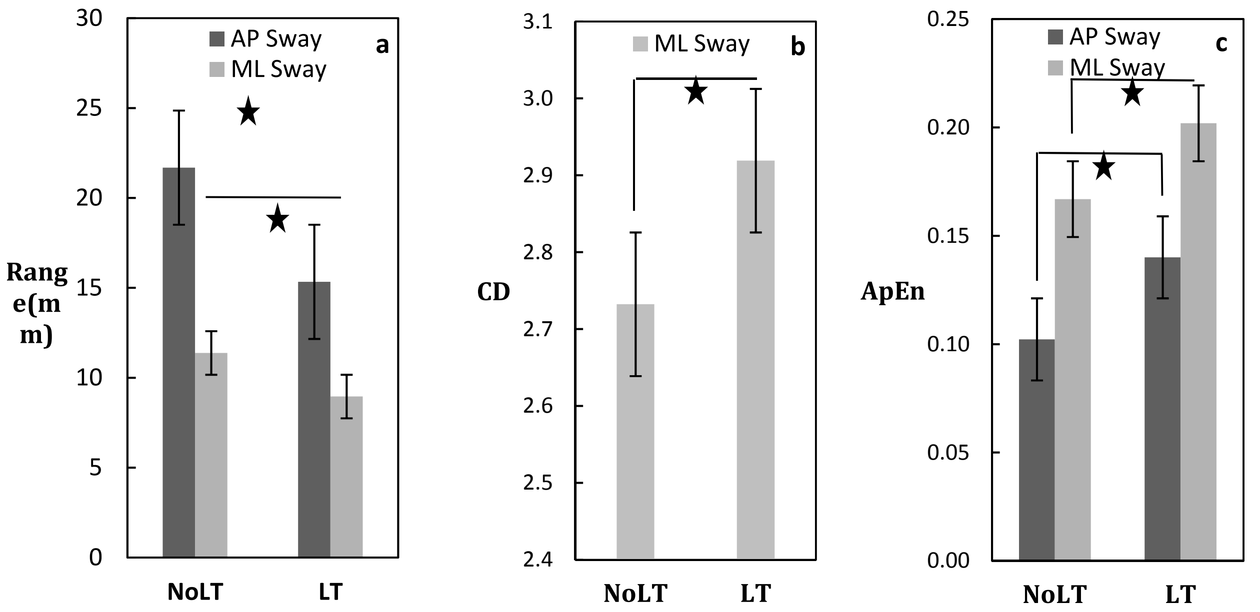

Figure 2. Light Touch Effect on Center of Pressure Range in Anterio-Posterior (AP) and Medio-Lateral (ML) directions (a), Correlation Dimension (CD) in Medio-Lateral (ML) direction (b) and Approximate Entropy (ApEn) in Anterio-Posterior (AP) and Medio-Lateral (ML) directions (c). NoLT: No Light Touch, LT: Light Touch. * indicates a significant difference (p≤0.05).

linear COP measures of the study, except the Correlation Dimension. VT caused a reduction of COP sway and the increase of COP ApEn and SampEn but no change in the COP Correlation Dimension. Finally, simultaneous LT and VT led to a greater reduction of postural sway compared to the conditions with only the LT task or only the VT task, suggesting an additional benefit of performing these two tasks during quiet stance in young, healthy adults. Related findings reflecting the two hypotheses and the question of the study will be discussed in three main parts as follows.

LT effect on postural control dynamics

Regarding the expected effects of LT on postural control, the first hypothesis was confirmed as COP sway range and SD reduced with finger LT in both AP and ML directions in the current study (Figure 2 a). These results confirm previous ones about the LT effects on the COP (2, 4, 20). In addition, ApEn, SampEn, and Correlation Dimension of COP sway increased in the LT condition (Figure 2 b, c).

Finger LT in a quiet stance increased COP time series complexity, which reflects that balancing requires less attention (23). Similarly, a recent study reported an increase in COP SampEn with LT and stated that touching an external surface generated an external focus of attention for postural stability (20). LT increased the attractor dynamics dimension in the current study. Indeed, engaging the brain in a second task (LT) reduces the attentional demands for postural control and makes it be performed more automatically (23). The automatic process of postural control is associated with greater subcortical activation rather than cortical activation and is evoked by sequential activity of neurons in the brainstem and spinal cord (30). This level of postural control is done by reflexes and increases muscle activation and joint stiffness, which could increase dimensionality in the attractor dynamics. Thus, an increase of the attractor dynamic dimension with LT could indicate the change of postural control strategy from an attentional, cortical level to an automatic, subcortical level. The increase of Correlation Dimension with maintaining the LT on a suspended curtain was also reported by Lee and her colleagues (19).

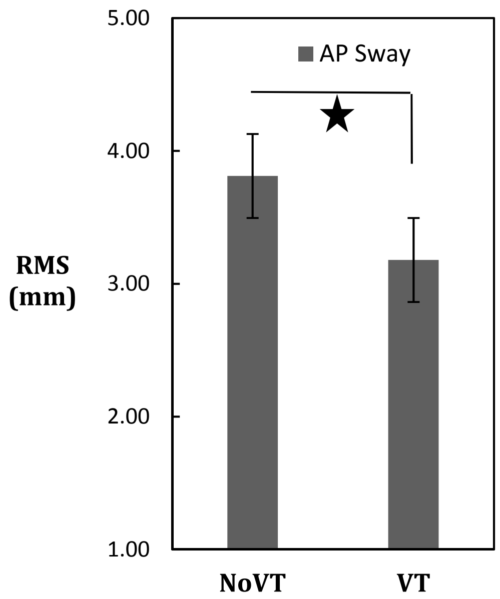

Figure 3. Visual Tracking Effect on Center of Pressure Root Mean Square (RMS) in Anterio-Posterior (AP) direction. NoVT: No Visual Tracking, VT: Visual Tracking. * indicates a significant difference (*P*≤0.05).

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They claimed that LT in a stable standing condition increases postural task constraint and dimensionality consequently. Also, a research study by Lee and her colleagues replicated the increase of the attractor dimension due to LT (13). The authors ascribed this change to "precision demands" of postural task which was applied by maintaining the finger contact on a load cell and introduced the precision demand as a control parameter that constrains postural control system organization.

VT effect on postural control dynamics

Regarding the expected effects of VT on postural control, the second hypothesis was supported by linear and non-linear COP measures of the study, except the Correlation Dimension. COP linear variables significantly decreased (Figure 3) and its entropy significantly increased (Figure 4) with VT but the Correlation Dimension did not change significantly.

SDAP and RMSAP of COP decreased in our research (Figure 3), which is consistent with previous studies (5, 8, 9). During precise vision tasks, the amplitude of gaze shifts is continuously adapted as a function of the magnitude of postural oscillations by the CNS because it requires moving the eyes to fixate on a very precise location (5). Besides, a research study indicated that a visual search task could lead to a decrease in COP sway during standing (18). However, some studies observed an augmented fluctuation during visual pursuits (6, 7, 31) caused by an increase in retinal flow (32). In the current study, we observed the stabilizing effect of VT in shoulder width stance condition whereas studies with opposite results examined the effect of VT in feet together conditions (7) or one leg stance (31). Under an easy postural task, adaptive mechanisms are available for efficient postural control, but under a more challenging postural condition, it is more difficult to obtain sufficient compensation (33). The difficulty of the foot position during stance might determine the VT effect on postural stability (7).

COP complexity (ApEnAP and SampEnAP) increased in our research (Figure 4). These findings support a recent study that reported an increase in COP SampEn during VT (7). Similarly, an increase in entropy by use of external focus (22) and cognitive task (uttering backward names read out aloud by the investigator) (23) have been demonstrated. The adjustment of oculomotor behavior and postural control in a synergistic manner to perform the VT might explain the improvement of postural stability while performing VT in the current study.

Therefore, tracking a moving target without head movements might be useful in balance training in populations with complexity loss, such as Parkinson's Disease, faller elderly individuals, and those who recovered from osteoporotic fractures (34-36).

As the study results show, the VT effect for the COP Correlation Dimension was not significant. This means that the gaze-shift task used in the study could not change postural control system dimensionality. Depending on the difficulty and attentional requirement of the oculomotor tasks, the effect of these tasks on postural stability is different (33).

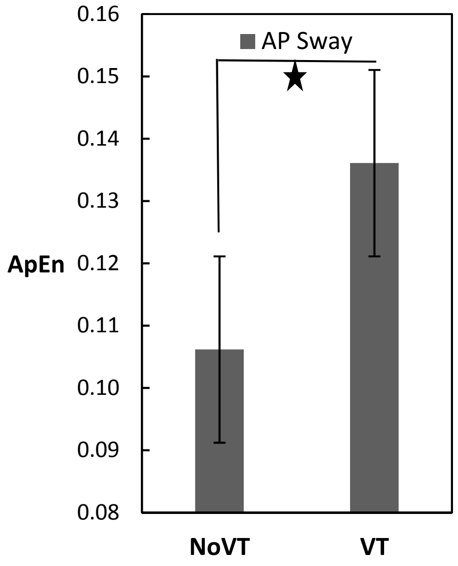

Figure 4. Visual Tracking Effect on Center of Pressure Approximate Entropy (ApEn) in Anterio-Posterior (AP) direction. NoVT: No Visual Tracking, VT: Visual Tracking. * indicates a significant difference ($P \leq 0.05$).

Thus, an increase in the difficulty of VT could probably influence this feature of the postural control system. The assessment of the visual task difficulty effect on COP Correlation Dimension is suggested for future studies.

Combined Performance of LT and VT

In the current study, we aimed to answer the question whether there is an additional benefit of simultaneous performance of LT and VT compared to the individual performance of LT or VT for linear and non-linear COP measures of the quiet stance postural control in young adults. We found that, compared to the N condition, the COP sway reduced more in the VTLT condition than when LT or VT was performed individually (Table 1). In addition, the Correlation Dimension, ApEn, and SampEn of COP showed an added increase when LT and VT were performed together compared to the N condition, than when only LT or when only VT was performed compared to the N condition (Table 2). This finding shows that there is an additional benefit for both linear and non-linear behavior of postural control when these tasks are combined compared to their individual performances. Indeed, postural control is better adapted to perform LT and VT, and there is a further adaptation of postural control to perform both LT and VT together.

No previous investigation has evaluated the effect of concomitant VT while performing LT on stance stability. However, there are a few studies that examined the effect of combined LT and visual search or LT and Stroop test on linear measures of COP during quiet stance (15, 17, 18). One of these studies demonstrated the combined effect of LT and visual search for COP sway in young individuals (18) which supports our finding in the current study. The authors reported, compared to the control condition, the reduction of COP sway was higher in dual-tasks (visual search+LT) than in the single-task (visual search only or

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LT only) and they assumed that LT and visual search are controlled by different supraspinal centers that are not directly related to each other (18). The visual task used in the study of dos Santos et al. was visual searching and counting the frequency of one specific letter among other letters in a poster which is more difficult than the visual tracking task in our study. However, they examined their participants in shoulder width stance which is similar to the present study. This shows that both easy and difficult visual tasks could provide additional benefits for postural stability when performed simultaneously with LT in an easy postural task in young adults. The effect of the concomitant Stroop test while performing LT in standing has been evaluated in the elderly (17). This study reported no interaction effect of LT and Stroop test for most of the COP measures of the study (time to contact, dynamic margin of stability, COP velocity, and the frequency corresponding to 80% of the total power). However, this interaction relation for COP sway magnitude was statistically significant which means that the decrease of this parameter while performing the Stroop test was stronger for the single-task condition (Stroop test only) than for the dual-task condition (Stroop test+LT) and the researchers speculated the floor effect for LT on postural sway in the elderly (17). They assumed that during the light touch task, the postural control system decreased COP sways to the maximum limit and consequently was not able to further reduce postural sway when the Stroop test was added. A greater reduction of COP sway during LT in older adults compared to young adults was revealed by another experiment (15). However, the researchers did not speculate the floor effect for LT because no interaction between LT and visual search was found for COP measures in both healthy young individuals and the elderly population (15). The additional benefit of the simultaneous performance of LT and visual search for COP sway compared to their individual performance was not evaluated in the mentioned study.

Conclusion

LT, as a supra-postural task, caused an increase of COP entropy in standing. This increment of complexity is concurrent with the increment of dimensionality, which could demonstrate the change of postural control strategy during LT condition. In addition, entropy increased with the VT in the shoulder-width quiet stance. Combining VT and the LT task provided an additional benefit for both linear and nonlinear features of the postural control system during quiet stance in healthy young adults. Adding VT to balance exercises using LT should be explored as an effective means to improve standing stability.

Lastly, we acknowledge that our study has a limitation. The color of the background was not the same in the 4 test conditions. The background color used for “X” in conditions N and LT was white, and the background color used for the moving circle in conditions VT and VTLT was very light pink. However, white color and very light pink color do not have much contrast. The difference in the color of the backgrounds could be a confounding factor that was not controlled in our study.

Authors’ Contributions

Conceptualization: [Mina Mirahmadi, Reza Salehi]; Methodology: [Mina Mirahmadi , Amir Homayoun Jafari, Reza Salehi, Soheil Mansour Sohani]; Formal analysis and investigation: [Mina Mirahmadi , Amir Homayoun Jafari, Reza Salehi, Soheil Mansour Sohani]; Writing - original draft preparation: [Mina Mirahmadi]; Writing - review and editing: [Mina Mirahmadi , Amir Homayoun Jafari, Reza Salehi, Soheil Mansour Sohani]; Supervision: [Amir Homayoun Jafari, Reza Salehi, Soheil Mansour Sohani].

Ethical Considerations

The ethics committee of IUMS approved the research (ethic code: IR.IUMS.REC.1398.847).

Acknowledgment

The authors thank Dr. Ahmad Reza Keihani who assisted in the non-linear analysis of COP data.

Conflict of Interests

The authors declare that they have no competing interests.

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