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Review

The effects of textured materials on static balance in healthy young and older adults: A systematic review with meta-analysis

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ABSTRACT

Background: Standing on textured materials can improve static balance, potentially by modulating somatosensory inputs from the soles of the feet.
Research question: To synthesise and quantify the immediate effects of textured materials on static balance in healthy young and older adults.
Methods: Primary outcomes were the centre of pressure (COP) displacement and velocity, during eyes open and eyes closed conditions. Ten crossover studies (n = 318, 58% female) met the inclusion criteria. A random effects meta-analysis model derived pooled standardised mean differences (SMD; Hedges g) to quantify the effects of textured materials. Heterogeneity was quantified with the tau-statistic (τ). A 95% prediction interval quantified the likely range of true effects on COP outcomes in similar future studies.
Results: There was a small to moderate beneficial effect for textured materials vs control conditions in: COP displacement during both eyes open (SMD: 0.29; 95% CI -0.06 to 0.64; τ = 0.32) and eyes closed (SMD: 0.75; 95% CI 0.18 to 1.33; τ = 0.55). A trivial to small beneficial effect was observed in COP velocity during eyes open (SMD: 0.14; 95% CI -0.14 to 0.43; τ = 0.18) and eyes closed (SMD: 0.20; 95% CI 0.01 to 0.40; τ = 0.18) for textured materials. The 95% prediction intervals showed texture may not consistently provide beneficial results across studies for all outcomes: COP displacement EC (-0.61 to 2.12), EO (-0.54 to 1.12), COP velocity EC (-0.27 to 0.68) and EO (-0.44 to 0.73).
Significance: Overall, textured materials improved balance, but these effects were heterogeneous. This research may therefore inform applied investigations into balance improvements for healthy populations, for example, in functional movements and sports.

1. Background

Maintenance of upright balance for humans can be difficult due to a high centre of mass over a relatively small base of support [1]. Even when standing statically (often termed quiet standing), the body still produces small amounts of sway [2]. This postural sway is an indicator of displacement and motor corrections to maintain the centre of gravity within the base of support [3].

Postural control is achieved via the central nervous system (CNS), which collates afferent information arriving from visual, vestibular and somatosensory sources [4]. The afferent information received from these sources allows for an internal representation of the body's position and location in space. When balance is threatened by either an external or internal perturbation, the CNS can initiate an appropriate muscular response. This is accomplished by comparing the collated afferent information to the internal model (expected state) to elicit a motor response, which will maintain the centre of mass within the limits of stability [5]. These signals are however plagued by noise [6]. It would therefore be beneficial if an intervention could enhance the available information arriving to the CNS. This would allow for a reduction of the noise for the purpose of internal modelling and allow for quicker, efficient and more accurate motor responses when necessary.

A key somatosensory input for the CNS is derived from the cutaneous mechanoreceptors located in the soles of the feet [7,8]. The afferent information received from these specialised sensors are particularly important as they contact the standing surface, providing vital information regarding the body in space [9]. A reduction in the information available through these receptors can equate to poorer postural performance during quiet standing [10]. Mechanically stimulating the plantar skin, via application of a fixed pin matrix to participants'

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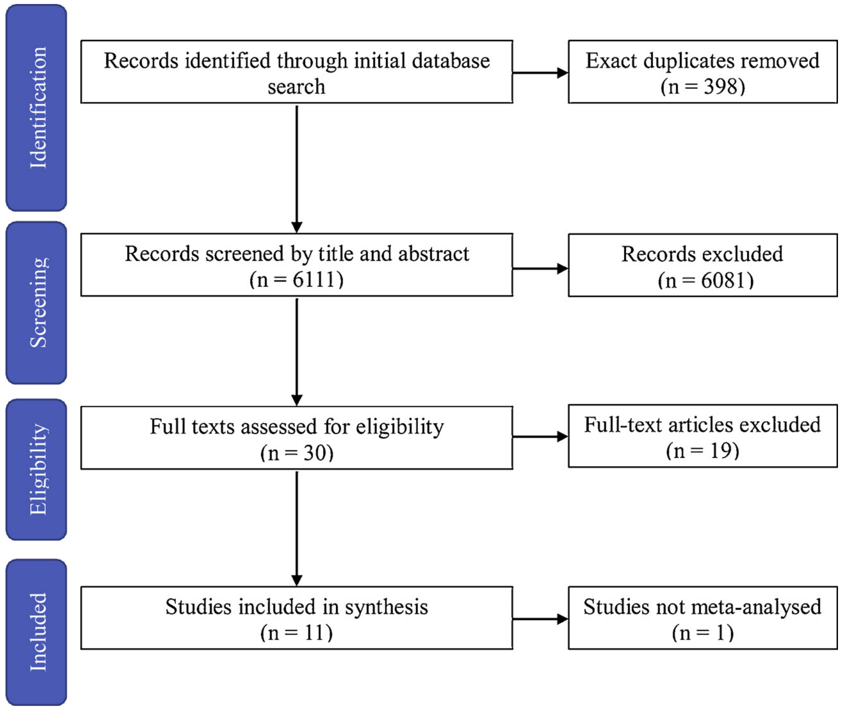


Fig. 1. Flow chart of study selection.

forefeet, has been shown to improve postural sway measures [11]. This intervention, however, was only applied to a small region of the soles of the feet. By utilising a texture that covers the entirety of the plantar surface of the feet, more mechanoreceptors could be activated and therefore provide greater stimulation. To this end, similar benefits on static balance have been observed when introducing texture to the entire soles of the feet in healthy young and older participants [12–14]. Application of such texture has been accomplished via either a textured surface [13,15–18] or textured insoles [12,14,19–22]. When referring to each texture modality individually we will use this terminology. When discussing texture as a collective it will be termed 'textured material'. Textured material has the potential of becoming a relatively inexpensive and viable way of improving postural control, especially through the textured insoles medium which can be worn within the shoes and therefore have greater application in everyday life.

Most studies on the effects of textured materials involve a crossover design, with relatively small sample sizes. Meta-analyses can be useful to quantify the effects of an intervention with greater precision from a pooled estimate. A standardised mean difference (SMD) is often reported. The SMD is an effect size, which compares the average performances of two groups or two conditions on a pre-determined outcome [23]. In the current case this would be textured versus control. The difference in means is calculated and expressed as a fraction of the standard deviation. So, an SMD of 1 indicates that there is a mean difference equivalent to one standard deviation. These effect sizes correspond to the strength of the intervention, with suggested values been: trivial < 0.2, small 0.2-0.3, moderate 0.4-0.8, and large > 0.8 [24]. A prior meta-analysis, assessing multiple subpopulations, showed that upright balance was reduced during texture exposure (SMD: -0.24 [25]). This change in the SMD represents a small improvement in balance outcomes. Another meta-analysis assessed textured and stimulating insoles in those with either multiple sclerosis or Parkinson's disease, concluding a lack of effect on COP displacement (SMD: 0.07) and COP velocity (SMD: -0.08 [26]). There is however a lack of recent studies within this analysis, with only two of the included studies [27,28] meeting the criteria for upright balance. Additionally, both previous meta-analyses do not report whether they merged multiple texture conditions to compare against a singular baseline, suggesting evidence of double counting [29]. A further concern of one of these studies [26] is the lack of reporting towards the imputation of a paired correlation coefficient for crossover studies. This casts issues regarding how they arrived at the reported standard errors and confidence intervals, as they do not reflect the crossover nature of the within-subject designs [30]. The current review will address this issue via inclusion of a correlation coefficient. Furthermore, no review has clarified the effects of texture on upright balance solely in healthy younger and older adults. By quantifying the effects of textured materials on balance in healthy participants, we can assess the immediate adaptive responses of the CNS when it is free of impairment. Such studies can inform applied work attempting to both understand and improve balance in healthy populations. For example, in functional movements and in sporting performance. Characterising the effect of textured materials in this way provides a clear benchmark against which comparisons can be made to other populations who present with a higher risk of falling. Moreover, this approach will extend the existing knowledge base on textured material as a potentially cheap and viable way of improving balance. We therefore aimed to synthesise the evidence from previous studies investigating the effect of texture on static posturography in healthy young and older participants.

2. Review method

2.1. Search strategy

We searched MEDLINE, CINAHL, AMED, and SPORTDiscus databases, utilising the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA; see Fig. 1) approach [31]. The searches included detailed terms relating to the use of foot orthotics (textured insoles/surfaces), static balance control and sensorimotor feedback, all search terms with Boolean operators can be seen in Table 1. Searches were conducted from inception through February 2018.

2.2. Inclusion criteria

For inclusion, each study needed to meet the following criteria: assessed textured insoles or surfaces during data collection, the texture

Table 1
Terminology used for systematic search of databases.

Search	Query	Results
38	Healthy OR young OR older OR elderly AND Insole OR insoles OR surface OR surfaces OR textured insole OR textured insoles OR textured surface OR textured surfaces OR orthosis OR orthotics OR orthoses OR inserts OR shoe inserts AND Balance OR static balance OR posture OR postural control OR postural steadiness OR postural stability OR quiet standing OR motor control OR sensorimotor OR somatosensory OR mechanoreceptor OR mechanoreceptors OR feedback OR feedback OR sensory reweighting OR proprioception OR proprioceptive	6, 509
37	Balance OR static balance OR posture OR postural control OR postural steadiness OR postural stability OR quiet standing OR motor control OR sensorimotor OR somatosensory OR mechanoreceptor OR mechanoreceptors OR feedback OR sensory reweighting OR proprioception OR proprioceptive	657, 593
36	Proprioceptive	11, 020
35	Proprioception	15,656
34	Sensory reweighting	126
33	Feedback	170, 486
32	Mechanoreceptors	11, 898
31	Mechanoreceptor	2, 417
30	Somatosensory	41, 124
29	Sensorimotor	27, 453
28	Motor control	26, 504
26	Quiet standing	1, 815
25	Postural stability	5, 431
24	Postural steadiness	180
23	Postural control	11, 090
22	Posture	115, 104
21	Static balance	3, 257
20	Balance	291, 237
19	Insole OR insoles OR surface OR surfaces OR textured insole OR textured insoles OR textured surface OR textured surfaces OR orthosis OR orthotics OR orthoses OR inserts OR shoe inserts	1, 270, 016
18	Shoe inserts	331
17	Inserts	14, 742
16	Orthoses	12, 887
15	Orthotics	9,706
14	Orthosis	14, 670
13	Textured surfaces	539
12	Textured surface	580
11	Textured insoles	44
10	Textured insole	40
9	Surfaces	273, 299
8	Surface	1, 156, 234
7	Insoles	2, 467
6	Insole	2, 263
5	Healthy OR young OR older OR elderly	2, 795, 995
4	Elderly	317, 773
3	Older	537, 898
2	Young	1, 397, 088
1	Healthy	888,719

must have contacted the whole plantar surface of the foot, and a control condition was present (e.g. no texture). Participants were either healthy young (< 55 years old) or older adults (≥55 years old) and data was collected via posturography (COP) during static balance.

2.3. Exclusion criteria

Studies were excluded if the surface/insole provided vibratory or mechanical stimulation, assessed non-textured materials, did not contact the whole plantar surface of the feet or the textured material only contacted one foot. Participants with pathologies or older adults with a history of falls were not considered. Studies that assessed gait were not included. Finally, manuscripts must have been available in English.

2.4. Study selection

Two members of the research team (RPWK) and (NB) independently selected the studies for inclusion in the systematic review. Potential studies were identified by examining the titles and abstracts, full copies of the text were obtained if they met the initial criteria of evaluating texture during quiet standing. Of the 30 full texts examined, 11 were included within this review. One study was excluded from the meta-analysis [21] due to their statistical reporting methods. This meant ten studies were included in the final meta-analysis.

2.5. Data synthesis

Included studies were assessed for quality independently by two authors (RPWK and NB), using established criteria (Physiotherapy Evidence Data-base [PEDro], http://www.pedro.org.au/english/downloads/pedro%20scale/). One author (RPWK) extracted data on the study methods, sample size, participants characteristics, centre of pressure displacement (mm) and velocity (mm/s) means and standard deviations (SD). These variables were created by pooling COP measurements, meaning a decrease in overall COP displacement or velocity equalled an improvement in postural sway [25]. To accomplish this, when studies reported separate force platform outcomes (e.g. anterior-posterior range, anterior-posterior velocity, and so on) the averages, that were presented in mm (displacement) or mm/s (velocity), were pooled to create a singular mean for a given study; for either COP displacement or COP velocity. All values attained were derived from means and standard deviations presented in the individual studies, which were averaged over multiple trials (3 or 4) collected over a range of data capture periods (10–80 s), per condition. One study attained their values from a single trial, per condition [13]. Since it is common to assess textured materials under eyes open and eyes closed conditions, we meta-analysed the attained data with consideration for this factor. Where the data was not reported in text or tables the data was digitised via the ‘grabit’ toolbox (https://uk.mathworks.com/matlabcentral/fileexchange/7173-grabit) in MATlab (MATLAB 2017a, The MathWorks Inc., Natick, MA).

2.6. Meta-analysis procedure

Meta-Essentials software [32]was used to conduct a random-effects (weighted variance method, Knapp-Hartung adjustment with Student’s *t*-distribution) meta-analysis of the mean difference in texture and control conditions for COP displacement and velocity for eyes open and closed conditions. Standardised mean differences (effect sizes) were calculated using the Hedge’s *g* as it accounts for small study bias, which Cohen’s *d* does not [33]. The inputted data included sample sizes, means and SD for textured and control conditions, and an imputed correlation coefficient to consider the fact that all meta-analysed studies involved a within-subjects design [30], as well as the fact that many authors did not directly report standard deviations of change, exact P-values and/or t/F values. These correlation coefficients were estimated from prior data collected in our laboratory, with a conservative $r = 0.8$ applied to each analysis. The software calculated the pooled standardised difference in means to determine the effect size [34]. The standardised mean differences and 95% confidence intervals (CIs) were calculated as summary statistics. The 95% CIs for each study were calculated using the t-statistic rather than the z-statistic, as coverage is more accurate using the t-statistic based approach [35,36].

Standardised mean difference (SMD) values were interpreted as follows; trivial < 0.2, small 0.2-0.3, moderate 0.4-0.8, and large > 0.8 [24]. A positive effect size indicates a reduction in the reported measure (COP displacement or velocity) when standing on texture and therefore an improvement in balance. Heterogeneity amongst the studies was quantified with the tau statistic (τ), which is a standard deviation expressing the typical variability of the mean between studies [37]. In addition, the meta-essentials software automatically calculates 95% prediction intervals (PI) for quantification of the expected range of true values for 95% of similar future studies, which is recommended to be reported [34].

3. Results

3.1. Overview

Eleven studies met the inclusion criteria for this systematic review, however, one study [21] was not included in the meta-analysis due to their reported statistics, which provided insufficient data for analysis. The ten studies included in the meta-analysis involved a total of 318 participants. All studies have been published in peer-reviewed scientific journals. The experimental trials in the ten studies assessed the initial effects of textured materials under foot. Additionally, all studies included within the meta-analysis were completed using a within-subjects research design. Wilson and colleagues [21] were the only study that ran a parallel, longitudinal study. Furthermore, all meta-analysed studies assessed participants in a single session. Finally, all studies collected COP data during exposure to a non-textured condition and textured materials.

The included studies are summarised in Table 2. The majority of studies recruited people of both male and female sex. The only exception was Wilson and colleagues [21] who utilised only females. Hatton and colleagues [13,15] were the solitary researchers to assess more than one texture type, assessing pyramidal and concave circular patterns, included within the meta-analyses. The study of Qiu et al. [14] assessed the same texture type but at varying degrees of density (hard insole, 320 density; soft insole, 270 density). Finally, Qu [22] also measured COP changes during four insole types, but only one provided textured stimulation to the sole of the foot (convex circular pattern). As we were concerned with the texture effect overall, and to avoid double counting, the textures were grouped together as a single intervention. COP changes were assessed during textured insole exposure in five studies, whilst the remaining five studies utilised a textured surface without shoes. Of the ten meta-analysed studies nine measured postural sway during bipedal standing only, whilst Corbin et al. [12] assessed both bipedal and unipedal standing. The mean PEDro score for the ten studies was 6.4(0.7), rating all studies to have a “good” methodological quality.

3.2. Participant demographics and insole characteristics

Of the 318 meta-analysed participants 184 (58%) were female and 134 (42%) were male. Seven of the studies assessed 170 (99 female) young participants (*M* age: 25.8(1.7) years) and six studies assessed 148 (85 female) older participants (*M* age: 70.3(2.5) years). Many different textures were used in the literature, a summary of which can be found in Table 2.

3.3. Meta-analysis

3.3.1. Centre of pressure (COP) displacement

Fig. 2 shows the immediate effect of textured material during eyes open (EO) and Fig. 3 for eyes closed (EC), regarding the COP displacement (mm) outcome. There was evidence of an effect for textured materials, compared with their corresponding controls, providing a reduction in COP displacement during EC (subtotal: SMD 0.75; 95% CI 0.18 to 1.33). This effect was smaller in the EO condition (subtotal: SMD 0.29; 95% CI -0.06 to 0.64). In both instances’ heterogeneity was present, with τ being 0.55 and 0.32, respectively. The 95% PI for texture effect in the EC condition was estimated to be -0.61 to 2.12, whilst the EO condition was estimated at -0.54 to 1.12.

3.3.2. Centre of pressure (COP) velocity

Fig. 4 illustrates the immediate effect of textured material during eyes open and Fig. 5 for eyes closed, regarding the COP velocity (mm/s) outcome. Textured materials reduced COP velocity, compared to their respective controls, for the EC condition (subtotal: SMD 0.20; 95% CI 0.01 to 0.40). Whereas there appeared to be a trivial effect during EO conditions (subtotal: SMD 0.14; 95% CI -0.14 to 0.43). The observed heterogeneity was lower in the velocity measure than the COP displacement measure; τ being 0.18 for both visual conditions. The 95% PI for texture effect in the EC condition was estimated to be -0.27 to 0.68, whilst the EO condition was estimated at -0.44 to 0.73.

4. Discussion

The improvement of balance *per se*, even in healthy individuals, is important because this can translate into reduced risk of falling or increased sports performance. Healthy populations can also act as a potential baseline for comparison to populations who are more likely to fall (e.g. normative values). To this end, the purpose of the present review and meta-analysis was to examine the effect of textured materials on COP measures in healthy young and older adults during static balance.

Overall, we observed a significant reduction in COP based measures both for displacement and velocity. COP displacement was reduced in both visual conditions – although the effect was amplified during EC, compared to EO (SMD: 0.75 vs. 0.29, respectively). The same trend was observed in the velocity variable, with a slightly greater effect during EC, compared to EO (SMD: 0.20 vs. 0.14, respectively). When examining the PIs, we can see that the effect of textured materials does not remain positive (the true effect does not cross zero) for any of the COP variables, although COP displacement during both visual conditions offer a possible large effect size in favour of textured materials (95% PI: EC = -0.61 to 2.12; EO = -0.54 to 1.12). The COP velocity variable appear to be less effected (95% PI: EC -0.27 to 0.68; EO -0.44 to 0.73). This would suggest that in 95% of similar studies we could expect to find a change in COP displacement within this range of magnitude [38]. The SMDs and 95% CIs suggest that balance can be improved in healthy young and older adults by standing on textured materials. If we, however, consider the high heterogeneity and 95% PIs it is evident these positive results were not ubiquitous. Accordingly, a more nuanced approach may be to recommend using textured materials in healthy adults, and potentially in populations at greater risk of falls, for the purpose of targeting specific components of balance where textured materials may prove to be an inexpensive intervention. Further work is therefore necessary to fully quantify the initial effects of textured materials on static balance.

The greater effect of texture when vision is occluded could be explained by the fact that vision is a major contributor to generating an internal model of the body in space [4]. When vision is occluded postural sway increases significantly compared with EO [39]. Textured materials may therefore have greater effect during EC, when there is more room for improvement (i.e. reduction of postural sway). A further possibility is that the greater effect of texture during eyes closed, relative to when eyes are open, may be attributed to sensory reweighting. This is a phenomenon whereby the relative contribution of each sensory system changes depending on environmental constraints [40]. Such reweighting would allow the internal model to maintain greater accuracy when visual feedback is not available. One conclusion that could be drawn from this finding is that textured materials may be most advantageous for those with visual impairments.

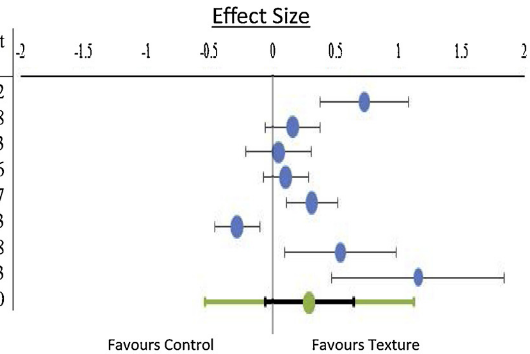
The observed effect in healthy individuals for textured materials on COP displacement displayed a small to moderate improvement in balance. With regards to the COP velocity outcome there was a trivial improvement in balance. It is thought that an increase in COP measures relates to an increased fall risk, due to slower reactive responses and reduced control of the direction of body movement [41]. This analysis

Table 2
Description of each studies population and texture type utilised.

Author(s) (date)	Studied population (Female; mean age)	Study method	Textured material	Indentations	Control condition
Annino et al. (2015)	17 healthy young adults (8; 25.4yrs)	Within-subjects, randomised order.	Firm textured disc.	Semi-circular shot pellets 3.5 mm high, diameter of 2 mm, centre to centre distance of 17 mm.	Force platform, no textured disc.
Corbin et al. (2007)	33 healthy young adults (17; 27.4yrs)	Within-subjects, counterbalanced order.	Plastic floor matting cut into insoles.	Small rounded plastic nodules 0.25 mm high.	Own athletic shoes, no insoles.
Hatton et al. (2009)	24 healthy young adults (17; 27.5yrs)	Within-subjects, randomised order.	Texture 1: Evalite pyramid, shore value A50. Texture 2: nora®Lumasoft mini non-slip, shore value A50.	Texture 1: Small pyramidal peaks 1 mm high, centre to centre distance of 2.5 mm. Total thickness 3 mm. Texture 2: convex circular pattern 1 mm high, diameter of 3 mm, centre to centre distance of 5 mm. Total thickness of 3 mm.	Smooth surface: Medium density EVA, 3 mm thickness, shore value A50.
Hatton et al. (2011)	50 healthy older adults (29; 75.1yrs)	Within-subjects, randomised order.	Texture 1: Evalite pyramid, shore value A50. Texture 2: nora®Lumasoft mini non-slip, shore value A50.	Texture 1: Small pyramidal peaks 1 mm high, centre to centre distance of 2.5 mm. Total thickness 3 mm. Texture 2: convex circular pattern 1 mm high, diameter of 3 mm, centre to centre distance of 5 mm. Total thickness of 3 mm.	Smooth surface: Medium density EVA, 3 mm thickness, shore value A50.
Palazzo et al. (2015)	40 healthy older adults (23; 70.2yrs)	Within-subjects, randomised order.	Firm textured disc.	Semi-circular shot pellets 3.5 mm high, diameter of 2 mm, centre to centre distance of 17 mm.	Force platform, no textured disc.
Palluel et al. (2008)	19 healthy young adults (9; 25.9yrs) 19 healthy older adults (10; 69yrs)	Within-subjects, counterbalanced order.	Semi-rigid PVC.	Spikes 5 mm high, diameter of 3 mm. 4 spikes per cm^2. Bigger spikes under medial arch, 10 mm high, diameter of 5 mm. 2 spikes per cm^2.	Smooth insoles: 3 mm thickness.
Palluel et al. (2009)	17 healthy young adults (11; 24.3yrs) 19 healthy older adults (11; 68.8yrs)	Within-subjects, counterbalanced order.	Semi-rigid PVC.	Spikes 5 mm high, diameter of 3 mm. 4 spikes per cm^2. Bigger spikes under medial arch, 10 mm high, diameter of 5 mm. 2 spikes per cm^2.	Smooth insoles: 3 mm thickness.
Preszner-Domjan et al. (2012)	50 healthy young adults (34; 23yrs)	Within-subjects, no randomisation or counterbalancing reported.	Thin elastic layer of rubber.	Spikes 7 mm high, diameter of 2 mm. 5 spikes per cm^2.	Force platform, no textured layer.
Qiu et al. (2012)	10 healthy young adults (4; 27yrs) 7 healthy older adults (3; 72yrs)	Within-subjects, randomised order.	Polyester and EVA.	Convex circular patterning, centre to centre distance of 10 mm.	Force platform, barefoot.
Qu (2015)	13 healthy older adults (8; 69.2yrs)	Within-subjects, randomised order.	Hard texture: ethylene-vinyl acetate, 320 density. Soft texture: ethylene-vinyl acetate, 270 density.	Both had granulations 3.1 mm high, diameter of 5 mm. Evenly distributed across the surface. Total thickness of 4.6 mm.	Smooth insoles.
Wilson et al. (2008)	40 healthy middle- aged females (51.1yrs)	Single blind randomised clinical trial over four weeks.	Texture 1: Evalite pyramid, shore value A50. Texture 2: nora®Lumasoft mini non-slip, shore value A50.	Texture 1: Small pyramidal peaks 1 mm high, centre to centre distance of 2.5 mm. Total thickness 3 mm. Texture 2: convex circular pattern 1 mm high, diameter of 3 mm, centre to centre distance of 5 mm. Total thickness of 3 mm.	Standard Hotter insoles: shore value A20.

Statistics for each study

Study name	Hedges' g (effect size)	CI Lower limit	CI Upper limit	Weight %
Annino et al 2015*	0.73	0.38	1.08	11.92
Corbin et al 2007^	0.16	-0.06	0.38	13.58
Hatton et al 2009*	0.04	-0.21	0.30	13.13
Hatton et al 2011*	0.10	-0.07	0.28	14.06
Palazzo et al 2015*	0.31	0.11	0.51	13.77
Preszner-Domjan et al 2012*	-0.28	-0.46	-0.10	14.03
Qiu et al 2012a^	0.54	0.09	0.98	10.98
Qiu et al 2012b^	1.16	0.47	1.84	8.53
	0.29	-0.06	0.64	100.00



a. Young adults; b. Older adults; *Textured surface; ^ Textured insoles

Fig. 2. Forest plot of effect sizes (standardised mean differences) with 95% confidence limits and meta-analysis weightings, for studies evaluating the effects of textured materials on COP displacement during eyes open conditions. The pooled effect size is given in the final row of the forest plot. The green line represents the width of the 95% prediction interval for the pooled effect size (-0.54 to 1.12). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

highlights the potential for textured materials to reduce postural sway and therefore improve balance. While these findings might extend to other populations, further work is needed to ascertain the effects of the more ecological valid textured insoles in different groups. This is made apparent by the lack of available studies in people with multiple sclerosis and Parkinson's disease, which were analysed by a previous meta-analysis, finding no effect of texture [26]. Their review compromised of six studies, of which only two studies [27,28] assessed textured materials effects on quiet standing outcomes. Overall 231 participants were included in the Alfuth review, equating to approximately a quarter less people than in the current review. The two studies which did assess texture similar to that reported here only assessed a small number of participants (n = 69), thus showing the need for further study in these sub-populations to investigate texture effects.

To assess COP movements, it is common practice to 'break-down' the overall COP into multiple outcomes, such as anterior-posterior and medial-lateral range, standard deviation, velocity, and overall sway path are some commonly reported outcomes. Given the mix of reported outcome variables across previous studies, we adopted the overall 'COP displacement' and 'COP velocity' as outcomes, as an individual analysis for each measure would not be possible due to differences in the studies chosen variables. Within the existing literature it is not uncommon to find a significant alteration to balance in only one outcome. For example, Hatton and colleagues [13] reported that only the medial-lateral standard deviation and range, during eye closure, were significantly reduced in a healthy older population. Whilst this is an important finding, given the relationship between increased medial-lateral sway and increased fall risk [41], our meta-analysis furthers these findings by providing evidence that overall COP displacement may be reduced in healthy adults, regardless of the vision condition. Given the healthy adult samples included in this review, this improvement may translate into reductions in injury risk during sport or act as a preventive for falls. Again, this would appear a fruitful avenue for future research.

All meta-analysed studies assessed the short term, initial, effects of textured materials on balance outcomes. The only study to examine textured insoles longitudinally was that of Wilson and colleagues [21], which found no effect of texture on any outcome variable in middle aged women at baseline and after 4-weeks of wear. Whilst we show here there is an initial adaptation to balance in healthy adults, further research is now called for to confirm the nature of the longitudinal effects of textured insoles. Such research will allow quantification of any possible habituation phase that may occur.

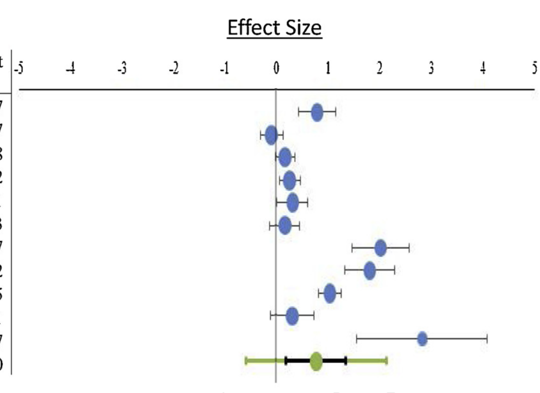
An important consideration of the current meta-analysis is that we only utilised ten studies, with a minimum of five studies in a single analysis (COP velocity EO). This is a potential limitation as meta-analyses are not immune to statistical power issues and by pooling data from a small amount of studies can still incur relatively low statistical accuracy (wide confidence interval for pooled effect [42]). Further work is therefore needed to clarify if textured insoles are a theoretically cheap and viable method of attaining these desired effects.

4.1. Conclusion

Textured materials can improve quiet standing balance in healthy young and older adults, which may equate to improved sports performance and reduced risk of falls. The SMD and 95% CI suggest that COP

Statistics for each study

Study name	Hedges' g (effect size)	CI Lower limit	CI Upper limit	Weight %
Annino et al 2015*	0.78	0.42	1.13	9.37
Corbin et al 2007^	-0.11	-0.33	0.11	9.87
Hatton et al 2011*	0.16	-0.02	0.34	9.98
Palazzo et al 2015*	0.25	0.04	0.45	9.92
Palluel et al 2008a^	0.30	0.00	0.60	9.61
Palluel et al 2008b^	0.15	-0.14	0.44	9.63
Palluel et al 2009a^	2.01	1.45	2.57	8.37
Palluel et al 2009b^	1.81	1.32	2.29	8.72
Preszner-Domjan et al 2012*	1.03	0.81	1.25	9.85
Qiu et al 2012a^	0.30	-0.12	0.72	9.21
Qiu et al 2012b^	2.82	1.55	4.08	5.47
	0.75	0.18	1.33	100.00



a. Young adults; b. Older adults; *Textured surface; ^ Textured insoles

Fig. 3. Forest plot of effect sizes (standardised mean differences) with 95% confidence limits and meta-analysis weightings, for studies evaluating the effects of textured materials on COP displacement during eyes closed conditions. The pooled effect size is given in the final row of the forest plot. The green line represents the width of the 95% prediction interval for the pooled effect size (-0.61 to 2.12). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Statistics for each study

Study name	Hedges' g (effect size)	CI Lower limit	CI Upper limit	Weight %
Annino et al 2015*	0.51	0.18	0.84	16.75
Corbin et al 2007^	0.04	-0.18	0.26	21.48
Hatton et al 2011*	-0.04	-0.22	0.14	23.46
Palazzo et al 2015*	0.29	0.09	0.50	22.23
Qu 2015^	-0.04	-0.40	0.32	16.08
	0.14	-0.14	0.43	100.00

a. Young adults; b. Older adults; *Textured surface; ^ Textured insoles

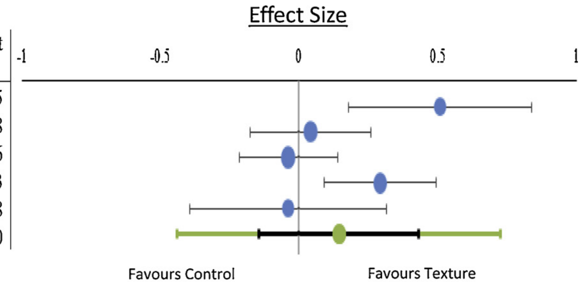


Fig. 4. Forest plot of effect sizes (standardised mean differences) with 95% confidence limits and meta-analysis weightings, for studies evaluating the effects of textured materials on COP velocity during eyes open conditions. The pooled effect size is given in the final row of the forest plot. The green line represents the width of the 95% prediction interval for the pooled effect size (-0.44 to 0.73). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Statistics for each study

Study name	Hedges' g (effect size)	CI Lower limit	CI Upper limit	Weight %
Annino et al 2015*	0.62	0.28	0.96	10.53
Corbin et al 2007^	0.16	-0.06	0.38	13.81
Hatton et al 2011*	-0.08	-0.26	0.09	15.13
Palazzo et al 2015*	0.18	-0.02	0.38	14.43
Palluel et al 2008a^	0.12	-0.18	0.41	11.80
Palluel et al 2008b^	0.01	-0.28	0.30	11.84
Palluel et al 2009a^	0.48	0.15	0.80	10.87
Palluel et al 2009b^	0.32	0.02	0.62	11.60
	0.20	0.01	0.40	100.00

a. Young adults; b. Older adults; *Textured surface; ^ Textured insoles

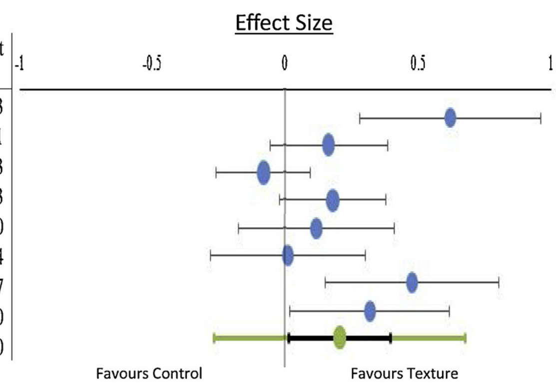


Fig. 5. Forest plot of effect sizes (standardised mean differences) with 95% confidence limits and meta-analysis weightings, for studies evaluating the effects of textured materials on COP velocity during eyes closed conditions. The pooled effect size is given in the final row of the forest plot. The green line represents the width of the 95% prediction interval for the pooled effect size (-0.27 to 0.68). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

displacement can be reduced using textured materials in healthy young and older adults, regardless of whether vision is available. Furthermore, COP velocity measures appear less affected by textured materials, with the effect only being significant in the EC conditions (SMD and 95% CI). The 95% PI results, however, suggest that textured materials may not always provide consistently beneficial effects in any COP outcome. Overall, the results are in favour of gaining modest beneficial improvements in balance from standing on textured materials in healthy populations, but further work is needed. Specifically, future studies should look to ascertain the longitudinal effects of textured insoles in healthy adult populations, and in other sub-populations, such as those with visual impairment or neurodegenerative diseases. This is because it is not yet clear how the specific advantages offered by textured insoles can improve balance in populations with different balance impairments.

Conflicts of interest

The authors have no conflicting interests.

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