

Evaluation of the Accuracy of Contactless Consumer Sleep-Tracking Devices Application in Human Experimentation: A Systematic Review and Meta-Analysis

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Supplemental Tables

Table S1. Search strategy for the meta-analyses.

Datab ase	Search Terms	Tota l Stu dies
<i>PubMed</i>		298
	(sleep*[Title/Abstract]) AND ((noncontact*[Title/Abstract]) OR (non-contact*[Title/Abstract]) OR (nonwearable[Title/Abstract]) OR (non-wearable[Title/Abstract]) OR (nontouch*[Title/Abstract]) OR (non-touch*[Title/Abstract]) OR (contact-free[Title/Abstract]) OR (contactless[Title/Abstract]) OR (*mattress*[Title/Abstract]) OR (sheet*[Title/Abstract]) OR (Emfit[Title/Abstract]) OR (Beddit[Title/Abstract]) OR (EarlySense[Title/Abstract]) OR (RestOn[Title/Abstract]) OR (Dot[Title/Abstract]) OR (Withings[Title/Abstract]) OR (SleepScore[Title/Abstract]) OR (ResMed[Title/Abstract]) OR (Somnofy[Title/Abstract]) OR (Nemuri SCAN[Title/Abstract]) OR (Isleep[Title/Abstract]) OR (Sonomat[Title/Abstract]) OR (SleepWise[Title/Abstract]) OR (SleepMinder[Title/Abstract])) AND (("Polysomnography"[Mesh]) OR (PSG[Title/Abstract]))	
<i>EMBASE</i>		864
	('sleep'/exp OR 'sleep' OR 'sleeping') AND ('non contact' OR noncontact OR nonwearable OR 'non wearable' OR nontouch OR 'non touch' OR contact-free OR 'mattress'/exp OR sheet% OR contactless OR emfit OR beddit OR earlysense OR reston OR dot OR withings OR sleepscore OR resmed OR somnofy OR 'nemuri scan' OR isleep OR sonomat OR sleepwise OR sleepminder) AND ('polysomnography'/exp OR psg)	
<i>Cochrane Library</i>		13
	#1 MeSH descriptor: [Sleep] explode all trees 6477 #8 (noncontact*):ti,ab,kw (Word variations have been searched) 696 #9 (non-contact*):ti,ab,kw (Word variations have been searched) 506 #10 (nonwear*):ti,ab,kw (Word variations have been searched) 53 #11 (non-wear*):ti,ab,kw (Word variations have been searched) 47 #12 (nontouch*):ti,ab,kw (Word variations have been searched) 27 #13 (non-touch*):ti,ab,kw (Word variations have been searched) 28 #14 (contact-free):ti,ab,kw (Word variations have been searched) 13 #15 (contactless):ti,ab,kw (Word variations have been searched) 35 #16 (*mattress*):ti,ab,kw (Word variations have been searched) 974 #17 (sheet*):ti,ab,kw (Word variations have been searched) 5235 #18 (Emfit):ti,ab,kw (Word variations have been searched) 2 #19 (Beddit):ti,ab,kw (Word variations have been searched) 4	

	#20 (EarlySense):ti,ab,kw (Word variations have been searched) 4 #21 (RestOn):ti,ab,kw (Word variations have been searched) 39 #22 (Dot):ti,ab,kw (Word variations have been searched) 1446 #23 (Withings):ti,ab,kw (Word variations have been searched) 23 #25 (SleepScore Max):ti,ab,kw (Word variations have been searched) 4 #26 (Somnofy):ti,ab,kw (Word variations have been searched) 1 #27 (Nemuri SCAN):ti,ab,kw (Word variations have been searched) 1 #28 (Isleep):ti,ab,kw (Word variations have been searched) 15 #29 (Sonomat):ti,ab,kw (Word variations have been searched) 1 #30 (SleepWise):ti,ab,kw (Word variations have been searched) 0 #31 (SleepMinder):ti,ab,kw (Word variations have been searched) 1 #32 (ResMed):ti,ab,kw (Word variations have been searched) 163 #33 #2 OR #3 OR #4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 #18 OR #19 OR #20 OR #21 OR #22 OR #23 OR #24 OR #25 8691 #35 MeSH descriptor: [Polysomnography] explode all trees 1959 #36 (PSG):ti,ab,kw (Word variations have been searched) 1530 #37 #27 OR #28 3224 #38 #1 AND #33 AND #34 AND #37 13	
Web of Scienc e		568
	1: TS=(sleep*) Results: 585334 2: TS=(noncontact*) OR TS=(non-contact*) OR TS=(nonwear*) OR TS=(non-wear*) OR TS=(nontouch*) OR TS=(non-touch*) OR TS=(contact-free) OR TS=(contactless) OR TS=(mattress*) OR TS=(sheet*) OR TS=(Emfit) OR TS=(Beddit) OR TS=(EarlySense) OR TS=(RestOn) OR TS=(Dot) OR TS=(Withings) OR TS=(SleepScore) OR TS=(ResMed) OR TS=(Somnofy) OR TS=(Nemuri SCAN) OR TS=(Isleep) OR TS=(Sonomat) OR TS=(SleepWise) OR TS=(SleepMinder) Results: 3562802 3: TS=(polysomnography) OR TS=(somnography) OR TS=(PSG) Results: 45568 4: #1 AND #2 AND #3 Results: 568	
Total after de- duplic ation		1744

Note. Tiab, title abstract; exp, “explodes” the category to include all terms under the umbrella term; ab,ti, abstract and title’ ti,ab,kw, title abstract keyword; tw, title word

Table S2. Results from qualified publications

First author (year)	Device	Results ¹
Zhang (2010) ¹	MMSM(RS-611)	• Overestimated SE ² (20.9±4.1%), light sleep ² (18.5±2.2%), REM (0.8±1.0%, NS ³); underestimated deep sleep ² (19.4±1.7%) ⁴ .

De Chazal (2011) ²	SleepMinder	<ul style="list-style-type: none"> All subjects: Overestimated TST (19.0±58.6 min), SE (4.8±14.4%); accuracy (78.0±11.1%), sensitivity (87.3±13.6%), specificity (50.1±19.8%)⁵; PPV⁶ (81.4±13.9%), NPV⁷ (66.1±24.3%); Low AHI: Overestimated TST (27.6±57.7 min), SE (7.0±14.1%); accuracy (81.3±10.0%), sensitivity (92.0±9.2%), specificity (51.1±19.1%)⁵; PPV (83.3±13.6%), NPV (72.4±21.4%); High AHI: Overestimated TST (8.2±58.6 min), SE (1.9±14.4%); accuracy (74.8±10.5%), sensitivity (81.1±15.8%), specificity (48.8±20.8%)⁵; PPV (78.9±14.2%), NPV (57.9±25.5%).
Hashizaki (2014) ³	SleepMinder	<ul style="list-style-type: none"> All subjects: Overestimated TST (12.7±63.9 min), SE (3.0±13.3 %); underestimated SOL (5.0±9.9 min), WASO (9.6±59.0 min); accuracy (84.1±11.1%), sensitivity (91.8±12.8%), specificity (37.6±21.8%)⁵; AHI≤15: Overestimated TST (12.4±31.8 min), SE (3.1±6.6%); underestimated SOL (3.7±7.5 min), WASO (10.4±31.1 min); accuracy (90.3±5.1%), sensitivity (96.0±4.9%), specificity (38.9±22.6%)⁵; AHI>15: Overestimated TST (12.8±75.0 min), SE (2.9±15.7%); underestimated SOL (5.6±10.9 min), WASO (9.1±68.9 min); accuracy (81.0±12.0%), sensitivity (89.7±14.9%), specificity (36.9±21.4%)⁵.
O'Hare (2014) ⁴	SleepMinder	<ul style="list-style-type: none"> Overestimated TST⁸ (35.0±13.3 min), SE⁸ (6.4±3.0 %); underestimated SOL⁸ (10.0±3.7 min), WASO⁸ (23.0±12.7 min); accuracy (85.6 ± 6.2%), sensitivity (95.3 ± 3.8%), specificity (38.9 ± 19%)⁵.
	SleepDesign (HSL-101)	<ul style="list-style-type: none"> Overestimated TST⁸ (43.0±12.0 min), SE⁸ (8.1±2.7 min); underestimated SOL⁸ (15.0±3.1 min), WASO⁸ (26.0±11.4 min); accuracy (85.6±6.4%), sensitivity (96.4±2.4%), specificity (35.8±14.2%)⁵.
	Actigraphy	<ul style="list-style-type: none"> Overestimated TST⁸ (50.0±11.5 min), SE⁸ (9.6±2.6 min); underestimated SOL⁸ (16.0±2.9 min), WASO⁸ (31.0±11.0 min); accuracy (85.5±6.3%), sensitivity (97.3±2.0%), specificity (33.9±12.7%)⁵.
Pallin (2014) ⁵	SleepMinder	<ul style="list-style-type: none"> All subjects: Overestimated TST (10±67 min, NS), SE (0.8±15.8%, NS); accuracy 77.3%, sensitivity 86.4%, specificity 51.8%⁵; AHI<5: Overestimated TST² (34±43 min), SE² (5.5±7.7%); accuracy 82.1%, sensitivity 93.9%, specificity 49.0%⁵; AHI 5-15: Overestimated TST⁸ (27±68 min), SE⁸ (3.4±13.5%); accuracy 81.2%, sensitivity 92.0%, specificity 46.6%⁵; AHI 15-30: Overestimated TST (-22±76 min, NS), SE (-6.9±21.1%, NS); accuracy 71.5%, sensitivity 76.3%, specificity 61.3%⁵; AHI >30: Overestimated TST (-4.5±71 min, NS), SE (0.1±16.5%, NS); accuracy 73.6%, sensitivity 82.1%, specificity 53.3%⁵.
	Actigraphy	<ul style="list-style-type: none"> Overestimated TST² (57±61 min), SE² (8.8±13.4%); accuracy 76.5%, sensitivity 93.8%, specificity 34.1⁵; PPV (83.3±13.6%); NPV (72.4±21.4%); AHI<5: Overestimated TST² (70±62 min), SE² (11.4±11.2%); accuracy 76.6%, sensitivity 95.5%, specificity 28.4%⁵; PPV (83.3±13.6%), NPV (72.4±21.4%); AHI 5-15: Overestimated TST² (57±49 min), SE² (7.2±11.5%); accuracy 79.2%, sensitivity 96.2%, specificity 32.9%⁵; AHI 15-30: Overestimated TST² (63±68 min), SE² (11.6±15.7%); accuracy 74.2%, sensitivity 93.0%, specificity 29.9%⁵; AHI >30: Overestimated TST² (44±68 min), SE⁸ (6.9±15.1%); accuracy 74.8%, sensitivity 90.4%, specificity 42.6%⁵.
Norman (2014) ⁶	Sonomat	<ul style="list-style-type: none"> Overestimated TST² (36.5±1.9 min).

Abad (2016) ⁷	SleepWise	<ul style="list-style-type: none"> Underestimated TST (7.2±8.8 min, NS).
Terjung (2016) ⁸	SleepMinder	<ul style="list-style-type: none"> Overestimated TST (34.0±10.5 min), SE (8.1±2.0%).
Norman (2017) ⁹	Sonomat	<ul style="list-style-type: none"> Overestimated TST (2.6±3.9 min, NS).
Tal (2017) ¹⁰	EarlySense	<ul style="list-style-type: none"> Sleep laboratory (setup I): accuracy 88.5%, sensitivity 89.7%, specificity 83.4%⁵; sensitivity in detecting light sleep 63.3%, deep sleep 53.6%, REM 40.0%; Home (setup II): accuracy 92.1%, sensitivity 95.4%, specificity 72.1%⁵; Home (setup III): accuracy 92.5%, sensitivity 95.1%, specificity 79.0%⁵.
Zaffaroni (2017) ¹¹	ResMed S+	<ul style="list-style-type: none"> Overestimated SOL (5.2±5.8 min, NS); underestimated TST (6.3±11.4 min, NS), SE (0.2±1.2 min, NS), SOL (0.7±3.5min, NS), light sleep (2.5±12.9 min, NS), deep sleep (3.0±7.5min,NS), REM (0.9±7.0 min, NS); accuracy in detecting wake 92%, deep sleep 88%,REM 89%; sensitivity in detecting sleep 62%, deep sleep 68%, REM 73%; specificity in detecting wake 95%, deep sleep 93%, REM 94%.
Chung (2018) ¹²	ResMed S+	<ul style="list-style-type: none"> Sensitivity in sleep/wake 75.3%, REM 14.6%; specificity in sleep/wake 43.1%, REM 89.6%.
Zaffaroni (2019) ¹³	ResMed S+	<ul style="list-style-type: none"> Overestimated TST (8.5±9.7 min, NS), light sleep (0.4±6.5 min, NS), REM² (13.7±3.8 min); underestimated SOL (0.7±3.5min, NS), WASO (7.8±6.1min, NS), deep sleep (5.8±5.6min, NS).
Schade (2019) ¹⁴	ResMed S+V1	<ul style="list-style-type: none"> Overestimated TST (17.7±61.4 min), light sleep (6.4±52.2 min), deep sleep (1.0±50.0 min), REM (10.2±26.6 min); accuracy 87.5%, sensitivity 94.8%, specificity 69.5%⁵; accuracy in detecting light sleep 64.0%, deep sleep 61.1%, REM 61.5%.
	ResMed S+V2	<ul style="list-style-type: none"> Overestimated TST (13.2±51.4 min), light sleep (12.8±41.2 min), REM (10.7±28.5min); underestimated deep sleep (-10.5±40.3 min); accuracy 87.6%, sensitivity 93.8%, specificity 73.1%⁵; accuracy in detecting light sleep 65.1%, deep sleep 52.2%, REM 61.6%.
	Actigraphy	<ul style="list-style-type: none"> Overestimated TST (43.4±53.5 min); accuracy 85.1%, sensitivity 96.6%, specificity 47.6%⁵.
Tuominen (2019) ¹⁵	Beddit Sleep Tracker	<ul style="list-style-type: none"> Overestimated TST² (43.5± 17.9 min), SE² (7.3±2.4%); underestimated SOL (3.2±6.6 min, NS), WASO² (32.6±8.8 min); specificity 42.1%; accuracy in detecting light sleep 55.6%, deep sleep 37.5%.
Miyata (2020) ¹⁶	SD 102	<ul style="list-style-type: none"> Total subjects: correlation TST⁸ (r=-0.151), SE² (r=-0.283); Men: correlation TST⁸ (r=-0.214), SE² (r=-0.377); Women: correlation TST (r=-0.042, NS), SE (r=-0.105, NS).
Stone (2020) ¹⁷	Beddit Sleep Monitor 3.0	<ul style="list-style-type: none"> Overestimated TST² (30.0±34.0 min), SE² (7.2±7.1%).
Nagatomo (2020) ¹⁸	Nemuri SCAN	<ul style="list-style-type: none"> Daytime: overestimated TST (337.2±38.0 min), SE (39.5±3.8%); Nighttime: overestimated TST (46.9±16.1 min), SE (10.9±3.1%); accuracy 68.4%; sensitivity 90.1%, specificity 38.8%⁵; PPV 66.8%, NPV 74.2%.
Toften (2020) ¹⁹	Somnofy	<ul style="list-style-type: none"> Overestimated TST (5.1±20.8 min), SOL (0.01±21.3 min), SE (1.0±4.3%), deep sleep(4.4±34.6min), REM (3.4±28.0 min); underestimated WASO (5.1±22.0 min), light sleep (2.7±35.7 min); accuracy 0.76, sensitivity 0.97, specificity 0.72; accuracy in detecting light sleep 0.75, deep sleep 0.74, REM 0.78.
Feng (2020) ²⁰	IR-UWB	<ul style="list-style-type: none"> Overestimated SE (0.4±1.8%), deep sleep (40.3±12.7min), REM (5.5±7.4 min); underestimated light sleep (85.3±20.5min).
Chinoy (2021) ²¹	EarlySense Live	<ul style="list-style-type: none"> Overestimated TST² (13.6±29.9 min), SE² (2.9±6.2%), SOL (0.8±8.2 min, NS), deep sleep² (35.9±52.4 min), REM (0.0±42.3 min, NS); underestimated WASO² (-15.3±19.5 min), light sleep² (-22.3±56.8 min); accuracy 0.90, sensitivity 0.96,

		specificity 0.47 ⁵ ; accuracy in detecting light sleep 0.63, deep sleep 0.81, REM 0.84; sensitivity in detecting light sleep 0.57, deep sleep 0.68, REM 0.64; specificity in detecting light sleep 0.69, deep sleep 0.84, REM 0.89.
	ResMed S+	<ul style="list-style-type: none"> Underestimated TST (-0.3±35.9 min, NS), WASO (-3.4±32.9 min, NS), REM (-31.9±27.4 min); overestimated SE (0.0±7.5%, NS), SOL⁸ (4.0±14.8 min), light sleep² (17.1±38.5 min), deep sleep² (14.5±35.4 min); accuracy 0.88, sensitivity 0.93, specificity 0.51⁵; accuracy in detecting light sleep 0.64, deep sleep 0.83, REM 0.85; sensitivity in detecting light sleep 0.67, deep sleep 0.59, REM 0.50; specificity in detecting light sleep 0.61, deep sleep 0.88, REM 0.95; PPV 0.93, NPV 0.62.
	SleepScore Max	<ul style="list-style-type: none"> Overestimated TST (7.5±34.8 min, NS), SE (1.6±7.2%, NS), SOL⁸ (4.4±12.0 min), light sleep² (22.7±37.9 min), deep sleep² (20.7±29.1 min); underestimated WASO⁸ (-12.1±34.9 min), REM² (-35.8±30.4 min); accuracy 0.88, sensitivity 0.94, specificity 0.50⁵; accuracy in detecting light sleep 0.64, deep sleep 0.84, REM 0.84; sensitivity in detecting light sleep 0.68, deep sleep 0.59, REM 0.49; specificity in detecting light sleep 0.60, deep sleep 0.88, REM 0.95.
	Actigraphy	<ul style="list-style-type: none"> Overestimated TST² (23.9±33.4 min), SE² (5.0±6.9%); underestimated SOL² (-7.6±8.4 min), WASO² (-16.6±32.9 min); accuracy 0.89, sensitivity 0.97, specificity 0.39⁵.
Edouard (2021) ²²	Withings Sleep Analyzers (WSA)	<ul style="list-style-type: none"> Overestimated TST⁸ (25.7±8.4min, NS), SE (0.1±1.5%, NS); underestimated WASO² (17.5±5.6 min).
Ellender (2021) ²³	Beddit	<ul style="list-style-type: none"> Overestimated SOL (44.6±59.4min, NS); underestimated TST² (53.4±92.7 min), SE (1.4±18.7 min, NS).
	ResMed S+	<ul style="list-style-type: none"> Overestimated SOL (35.6±46.6 min, NS), WASO² (27.2±50.4 min); underestimated TST⁸ (34.4±113.6min), SE (15.9±19.1min, NS).
Xue (2021) ²⁴	UWB Radar Sleep Monitoring System	<ul style="list-style-type: none"> Overestimated TST² (16.7±1.1min).
Hsiou (2022) ²⁵	Beddit 3.0	<ul style="list-style-type: none"> Overestimated TST (45.4±108.0 min), WASO (25.7±59.0 min); underestimated SE (-1.0±14.7%), SOL (-13.4±23.2 min).
	Beddit 3.5	<ul style="list-style-type: none"> Overestimated TST (1.57±7.4 min), SOL (6.4±6.1 min), WASO (21.7±14.9 min); underestimated SE (-1.1±2.1%).
	Actigraphy	<ul style="list-style-type: none"> Underestimated TST (-2.2±28.3 min), SE (-1.0±5.7%), SOL (-4.4±15.6 min), WASO (-3.2±29.3 min).
Kholghi (2022) ²⁶	EMFIT Quantified Sleep (QS)	<ul style="list-style-type: none"> Overestimated TST² (177.5±119.4 min), light sleep (94.2±90.4min), deep sleep (8.3±39min, NS), REM (75.0±40.87min); underestimated WASO² (44.7 ± 68.8min), SOL (5.6± 46.4 min, NS).

¹Accuracy, sensitivity, and specificity in detecting sleep epochs are reported unless otherwise specified.

² P<.01.

³ NS: not significant.

⁴ Differences for PSG and MMSM(RS-611) in light sleep, deep sleep, and REM Sleep staging composition ratio.

⁵ Epoch-by-epoch sleep–wake agreement between polysomnography and the CCSTD.

⁶ PPV, positive predictive value (percentage of epochs labeled as sleep that are correctly labeled).

⁷ NPV, negative predictive value (percentage of epochs labeled as wake that are correctly labeled).

⁸ P<.05.

Meta-subgroup analysis results of subgroups.

Table S3. Meta-subgroup analyses of sensors.

Outcome	Subgroup	N	Pooled mean	95% CI	I ² (P)	Z (P)
TST (min)	Piezoelectric	8	20.89	-0.74, 42.53	96.6%(0.000)	1.89(0.058)
	Pressure	3	80.29	6.83, 153.76	94.5% (0.000)	2.14 (0.032)
	Radiofrequency	2 3	16.27	14.26, 18.28	0.0% (0.460)	15.87(0.000)
	Infrared camera	1	-7.20	- 24.50, 10.10	— —	- 0.82(0.415)
SOL (min)	Piezoelectric	5	-2.48	-9.19, 4.22	50.8% (0.087)	- 0.73(0.468)
	Pressure	1	-5.60	- 21.09, 9.89	— —	-0.71 (0.478)
	Radiofrequency	1 1	-5.21	-7.16, -3.26	47.4% (0.040)	-5.24 (0.000)
WASO (min)	Piezoelectric	4	-2.29	- 26.95, 22.37	85.1% (0.000)	-0.18 (0.855)
	Pressure	2	-29.09	- 55.54, -2.65	76.5% (0.039)	-2.16 (0.031)
	Radiofrequency	1 0	-9.80	- 15.07, -4.53	0.0% (0.846)	-3.64 (0.000)
SE (%)	Piezoelectric	6	3.19	0.59, 5.79	14.9% (0.318)	2.40 (0.016)
	Pressure	2	5.16	-5.38, 15.71	90.0% (0.002)	0.96 (0.337)
	Radiofrequency	2 0	2.61	1.23, 4.00	22.6% (0.176)	3.69 (0.000)
Light Sleep (min)	Piezoelectric	1	-22.30	- 38.80, -5.80	— —	-2.65 (0.008)
	Pressure	1	94.20	61.59, 126.81	— —	5.66 (0.000)

	Radiofrecuency	8	1.57	-13.81, 16.95	75.4% (0.000)	0.20 (0.842)
Deep Sleep (min)	Piezoelectric	1	35.90	21.49, 50.31	— —	4.88 (0.000)
	Pressure	1	8.30	-9.39, 25.99	— —	0.92(0.358)
	Radiofrecuency	8	7.66	-3.48, 18.80	75.3% (0.000)	1.35(0.178)
REM (min)	Piezoelectric	1	0.00	-13.31, 13.31	— —	0.00 (1.000)
	Pressure	1	62.00	47.80, 76.20	— —	8.56 (0.000)
	Radiofrecuency	8	-3.97	-21.14, 13.21	93.4% (0.000)	-0.45 (0.651)

N, number of samples; CI, confidence interval; I², Heterogeneity; Z, Test of overall effect; TST, total sleep time; SOL, sleep onset latency; WASO, wake after sleep onset; SE, sleep efficiency; REM, rapid eye movement.

Table S4. Meta-subgroup analyses of device types.

Outcome	Subgroup	N	Pooled mean	95% CI	I²(P)	Z(P)
TST (min)	Mattress-based	11	36.96	18.16, 55.75	96.1% (0.000)	3.85 (0.000)
	Bedside	24	19.55	12.22, 26.88	20.6% (0.181)	4.91 (0.000)
SOL (min)	Mattress-based	6	-2.76	-8.47, 2.94	40.5% (0.136)	-0.949 (0.343)
	Bedside	11	-4.61	-6.56, -2.66	47.4% (0.040)	-5.236 (0.000)
WASO (min)	Mattress-based	6	-12.34	-28.76, 4.07	81.6% (0.000)	-1.474 (0.141)
	Bedside	10	-9.80	-15.07, -4.53	0.0% (0.846)	-3.64 (0.000)
SE (%)	Mattress-based	8	3.44	0.40, 6.48	56.7% (0.023)	2.218 (0.027)
	Bedside	20	2.62	1.23, 4.00	22.6% (0.176)	3.69 (0.000)
Light Sleep (min)	Mattress-based	2	35.07	-79.09, 149.22	97.4% (0.000)	0.602 (0.547)
	Bedside	8	1.57	-13.81, 16.95	75.4% (0.000)	2.00 (0.842)
Deep Sleep	Mattress-based	2	22.60	-4.44, 49.63	82.2% (0.018)	1.638

(min)						
	Bedside	8	7.66	-3.48, 18.80	70.2%	1.35
					(0.001)	(0.178)
REM(min)	Mattress-based	2	30.95	-29.81, 91.71	97.4%	0.998
					(0.000)	(0.318)
	Bedside	8	-3.97	-21.14, 13.21	93.4%	-0.45
					(0.000)	
						(0.651)

N, number of samples; CI, confidence interval; I², Heterogeneity; Z, Test of overall effect; TST, total sleep time; SOL, sleep onset latency; WASO, wake after sleep onset; SE, sleep efficiency; REM, rapid eye movement.

Table S5. Meta-subgroup analyses of participant types.

Outcome	Subgroup	N	Pooled mean	95% CI	I ² (P)	Z (P)
TST (min)	Healthy	18	13.44	6.57, 20.32	13.1% (0.297)	3.83 (0.005)
	Patients	7	19.91	4.23, 35.58	0.0% (0.590)	2.49 (0.013)
	Healthy+Patients	10	19.55	12.67, 36.80	96.6% (0.000)	4.02 (0.000)
SOL (min)	Healthy	12	-4.40	-7.39, -1.41	62.3% (0.002)	-2.88 (0.004)
	Patients	3	-5.66	-7.93, -3.38	0.0% (0.472)	-4.88 (0.000)
	Healthy+Patients	2	-5.01	-6.75, -3.27	0.0% (0.940)	-5.64 (0.000)
WASO (min)	Healthy	11	-9.76	-18.24, -1.28	59.2% (0.006)	-2.26 (0.024)
	Patients	3	-14.57	-23.67, -5.47	0.0% (0.501)	-3.14 (0.002)
	Healthy+Patients	2	-25.68	-60.15, 8.79	85.3% (0.009)	-1.46 (0.144)
SE (%)	Healthy	14	2.53	0.95, 4.10	30.6% (0.125)	3.15 (0.002)
	Patients	10	3.65	0.39, 6.90	55.1% (0.018)	2.19 (0.028)
	Healthy+Patients	3	3.00	0.19, 5.81	0.0% (0.983)	2.09 (0.036)
Light Sleep (min)	Healthy	8	4.96	-6.86, 16.78	65.6% (0.005)	0.834 (0.404)
	Patients	1	-85.32	-125.57, -	— —	-4.16 (0.000)

				-45.07		
	Healthy+Patients	1	94.20	61.59, 126.81	— —	5.662 (0.000)
Deep Sleep (min)	Healthy	8	8.43	-3.52, 20.39	77.3% (0.000)	1.38 (0.167)
	Patients	1	40.34	15.49, 65.19	— —	3.182 (0.001)
	Healthy+Patients	1	8.30	-9.39, 25.99	— —	0.920 (0.358)
REM (min)	Healthy	8	-4.69	-21.58, 12.20	93.3% (0.000)	-0.54 (0.586)
	Patients	1	5.45	-8.97, 19.87	— —	0.741 (0.459)
	Healthy+Patients	1	62.00	47.80, 76.20	— —	8.556 (0.000)

N: number of samples; CI, confidence interval; I²: Heterogeneity; Z: Test of overall effect; TST, total sleep time; SOL, sleep onset latency; WASO, wake after sleep onset; SE, sleep efficiency; REM, rapid eye movement.

Table S6. Meta-subgroup analyses of brands.

Outcome	Subgroup	N	Pooled mean	95% CI	I² (P)	Z (P)
TST (min)	SleepMinder	13	19.24	10.63, 27.84	0.0% (0.945)	4.38 (0.000)
	Sonomat	2	19.53	-13.69, 52.75	99.5% (0.000)	1.15 (0.249)
	ResMed S+	5	3.51	-5.74, 12.76	0.0% (0.659)	0.74 (0.457)
	Beddit	6	32.86	4.56, 61.15	0.0% (0.833)	2.28 (0.023)
	Others (Mattress-based)	4	59.51	17.00, 102.02	93.5% (0.000)	2.74 (0.006)
	Others (Bedside)	5	13.06	-0.50, 26.61	69.9% (0.010)	1.89 (0.059)
SOL (min)	SleepMinder	4	-5.08	-6.33, -3.82	3.8% (0.374)	-7.94 (0.000)

	ResMed S+	3	-1.76	-5.96, 2.45	12.8% (0.318)	-0.82 (0.413)
	Beddit	5	-2.69	-13.89, 8.51	49.8% (0.093)	-0.47 (0.638)
	Other (Mattress-based)	2	-0.99	-4.05, 2.08	0.0% (0.551)	-0.63 (0.527)
	Other(Bedside)	3	-9.05	-18.47, 0.37	72.9% (0.025)	-1.88 (0.060)
WASO (min)	SleepMinder	4	-11.01	-18.67, -3.34	0.0% (0.799)	-2.82 (0.005)
	ResMed S+	2	-5.73	-14.42, 2.97	0.0% (0.621)	-1.29 (0.197)
	Beddit	4	6.26	-31.62, 44.13	84.7% (0.000)	0.32 (0.746)
	Others (Mattress-based)	3	-22.09	-35.12, -9.05	60.8% (0.078)	-3.32 (0.001)
	Others(Bedside)	3	-16.39	-29.72, -3.06	0.0% (0.552)	-2.41 (0.016)
SE (%)	SleepMinder	1 3	4.50	2.95, 6.04	0.0% (0.772)	5.70 (0.000)
	ResMed S+	2	-0.12	-2.00, 1.76	0.0% (0.919)	-0.13 (0.900)
	Beddit	6	2.78	-1.86, 7.42	26.9% (0.233)	1.18 (0.240)
	Others (Mattress-based)	3	3.90	-0.71, 8.52	80.3% (0.006)	1.66 (0.097)

	Others(Bedside)	4	0.96	-1.53, 3.45	0.0% (0.977)	0.75 (0.452)
Light Sleep (min)	ResMed S+	5	7.92	0.00, 15.84	3.7% (0.385)	1.96 (0.050)
	Other (Mattress-based)	2	35.07	-79.09, 149.22	97.4% (0.000)	0.60 (0.547)
	Other(Bedside)	3	-21.55	-98.41, 55.32	91.8% (0.000)	-0.55 (0.583)
Deep Sleep (min)	ResMed S+	5	0.43	-9.43, 10.29	50.9% (0.086)	0.09 (0.932)
	Others (Mattress-based)	2	22.60	-4.44, 49.63	82.2% (0.018)	1.64 (0.101)
	Others(Bedside)	3	24.66	11.64, 37.68	13.8% (0.314)	3.71 (0.000)
REM (min)	ResMed S+	5	0.10	-20.12, 20.32	93.8% (0.000)	0.10 (0.992)
	Others (Mattress-based)	2	30.95	-29.81, 91.71	97.4% (0.000)	1.00 (0.318)
	Others(Bedside)	3	-11.72	-46.45, 23.00	91.1% (0.000)	-0.66 (0.508)

N, number of samples; CI, confidence interval; I², Heterogeneity; Z, Test of overall effect; TST, total sleep time; SOL, sleep onset latency; WASO, wake after sleep onset; SE, sleep efficiency; REM, rapid eye movement.

Supplemental Figures

	Risk of Bias				Applicability Concerns		
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard
Zhang(2010)	+	●	+	●	+	●	+
De Chazal(2011)	+	+	+	+	+	+	+
Hashizaki (2014)	●	+	+	●	+	+	+
Norman (2014)	+	+	+	●	+	●	+
O'Hare (2014)	●	+	+	+	+	+	+
Pallin(2014)	+	+	+	+	+	+	+
Abad(2016)	+	?	+	●	+	+	+
Terjung(2016)	●	+	+	+	+	+	+
Norman (2017)	+	+	+	●	+	+	+
Tal (2017)	?	+	+	+	?	●	+
Zaffaroni(2017)	●	+	+	●	+	+	+
Chung(2018)	+	+	+	●	+	+	+
Schade (2019)	●	+	+	●	+	+	+
Tuominen (2019)	●	+	+	●	+	+	+
Zaffaroni (2019)	?	+	+	+	+	+	+
Feng(2020)	+	+	+	●	+	●	+
Miyata (2020)	+	+	+	●	+	●	+
Nagatomo(2020)	+	+	+	●	+	●	+
Stone (2020)	●	+	+	●	+	+	+
Toften (2020)	●	+	+	●	+	+	+
Chinoy(2021)	?	+	+	?	+	+	+
Edouard (2021)	+	+	+	●	+	●	+
Ellender(2021)	+	+	+	●	+	+	+
Xue(2021)	+	+	+	+	+	●	+
Hsiou(2022)	●	+	+	●	+	+	+
Kholghi (2022)	?	+	+	●	+	+	+

● High
? Unclear
+ Low

Figure S1. Tabular presentation of QUADAS-2 results.

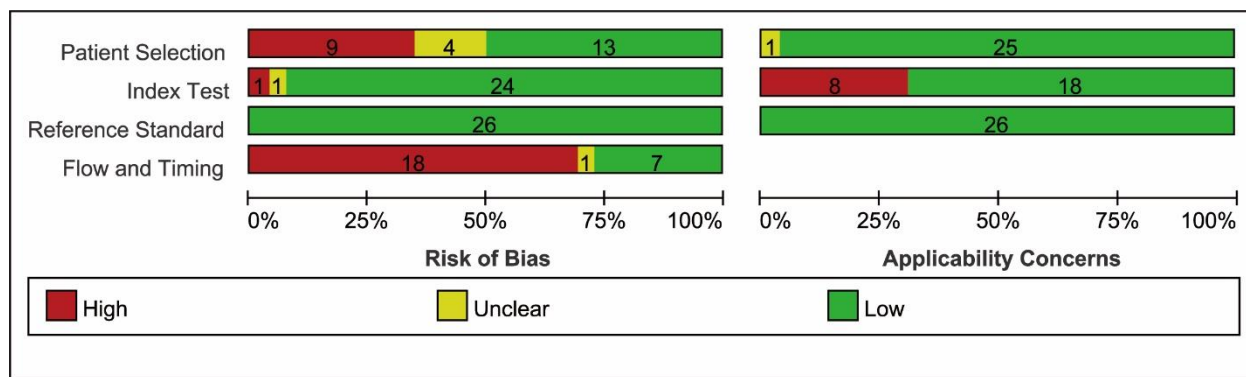
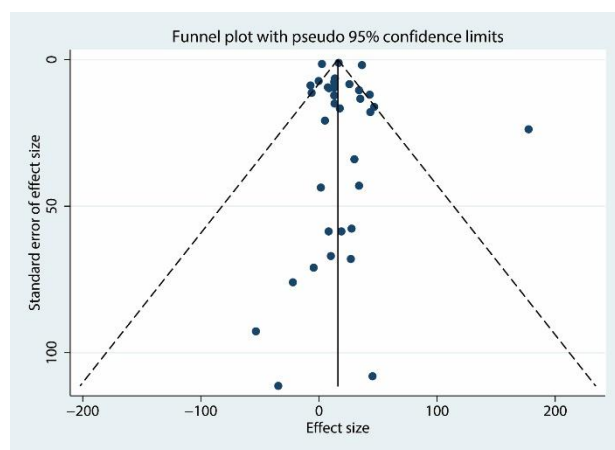
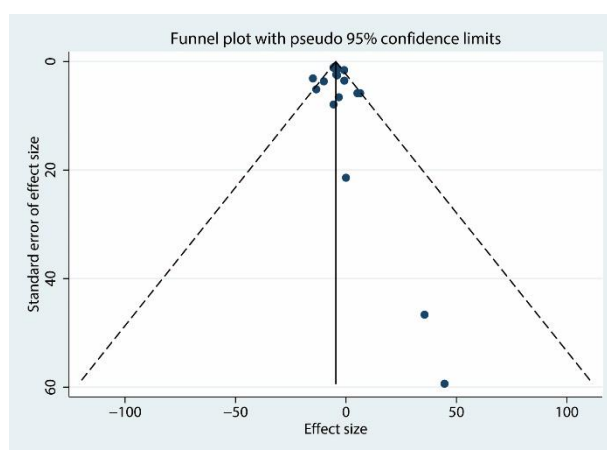


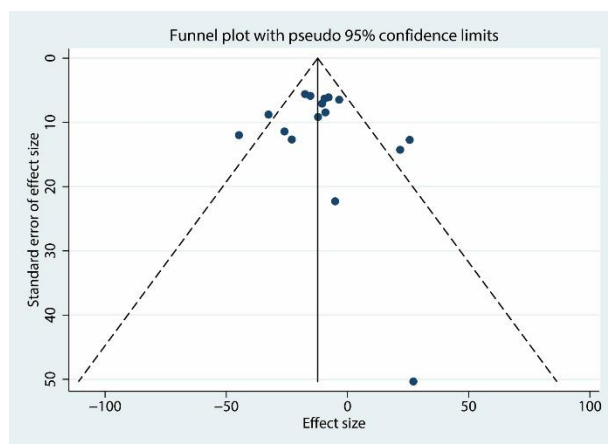
Figure S2. Graphical presentation of QUADAS-2 results.



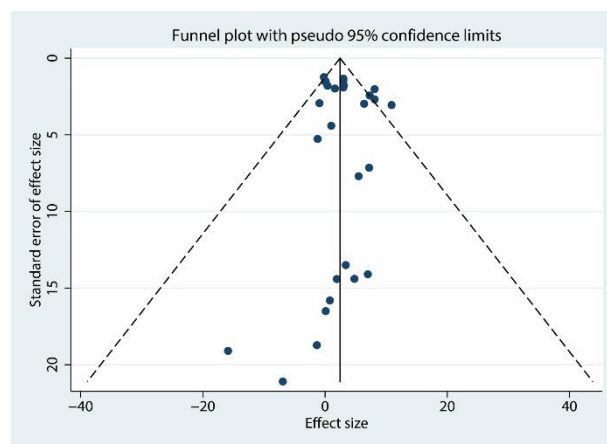
a.TST



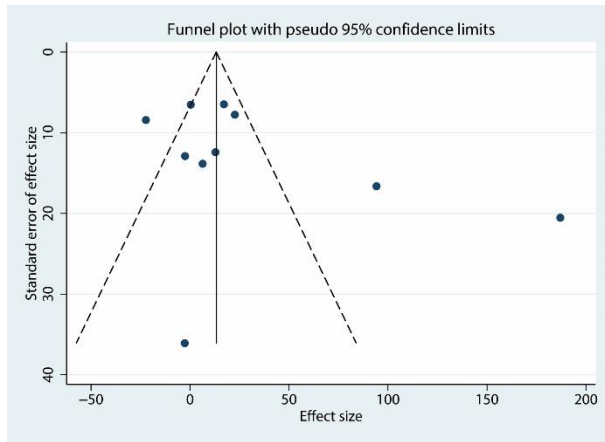
b.SOL



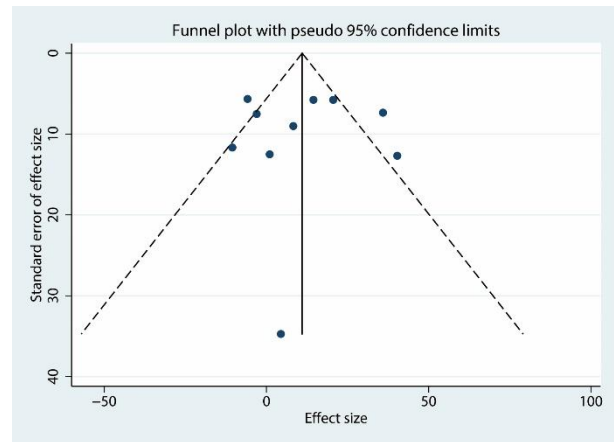
c.WASO



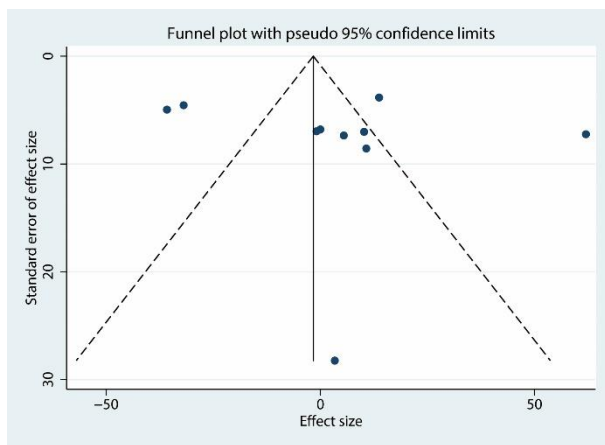
d.SE



e. Light Sleep



f. Deep Sleep



g. REM

TST, total sleep time; SOL, sleep onset latency; WASO, wake after sleep onset; SE, sleep efficiency, REM, rapid eye movement.

Figure S3. Funnel plot with pseudo 95% confidence limits.

Forest plot meta-analyses for subgroups.

This section lists the subgroups analysis results by expanding the search heterogeneity discussed in 3.4.1. Subgroup meta-analyses of TST, WASO, SOL, SE, light sleep, deep sleep, and REM were performed for the following variables: (1) the type of sensors, including the piezoelectric sensor, pressure sensor, radiofrequency sensor, and infrared camera; (2) the type of devices, including the mattress-based and bedside devices; (3) the variety of participants (ie, healthy participants, patients participants, and healthy and patients participants); (4) the brand of devices (the number of samples of the same brand greater than or equal to two will be included in the same group, and the other samples are divided into 1)other brands of bedside device, and 2)other brands of mattress device). The Forest plot meta-analyses are provided in Figures S4 to S31. A range of subgroups analysis results of sensors, device types, participant types, and brands are presented in Tables S3-S6.

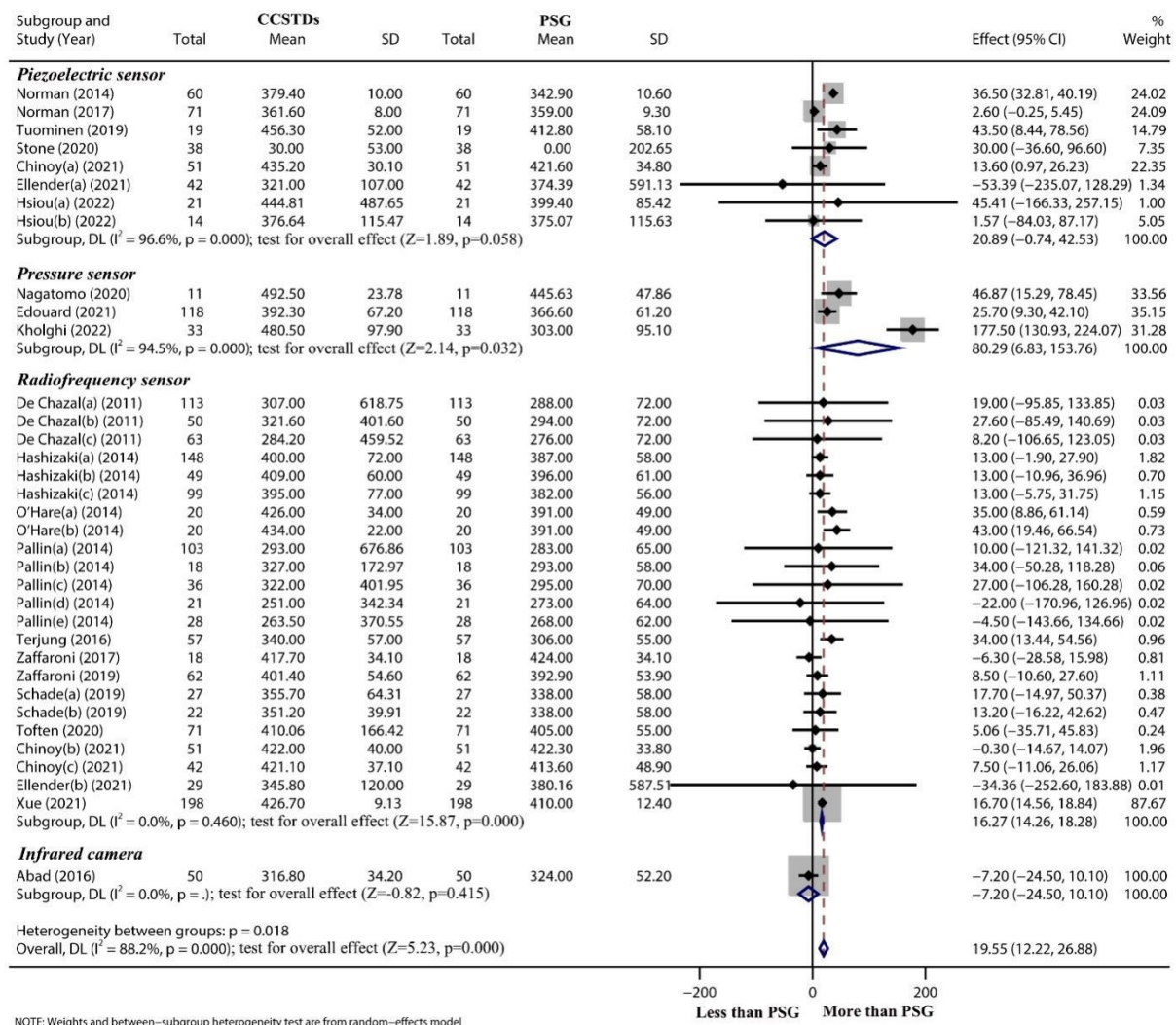


Figure S4. Forest plot meta-analyses for sensors subgroup -TST (min).

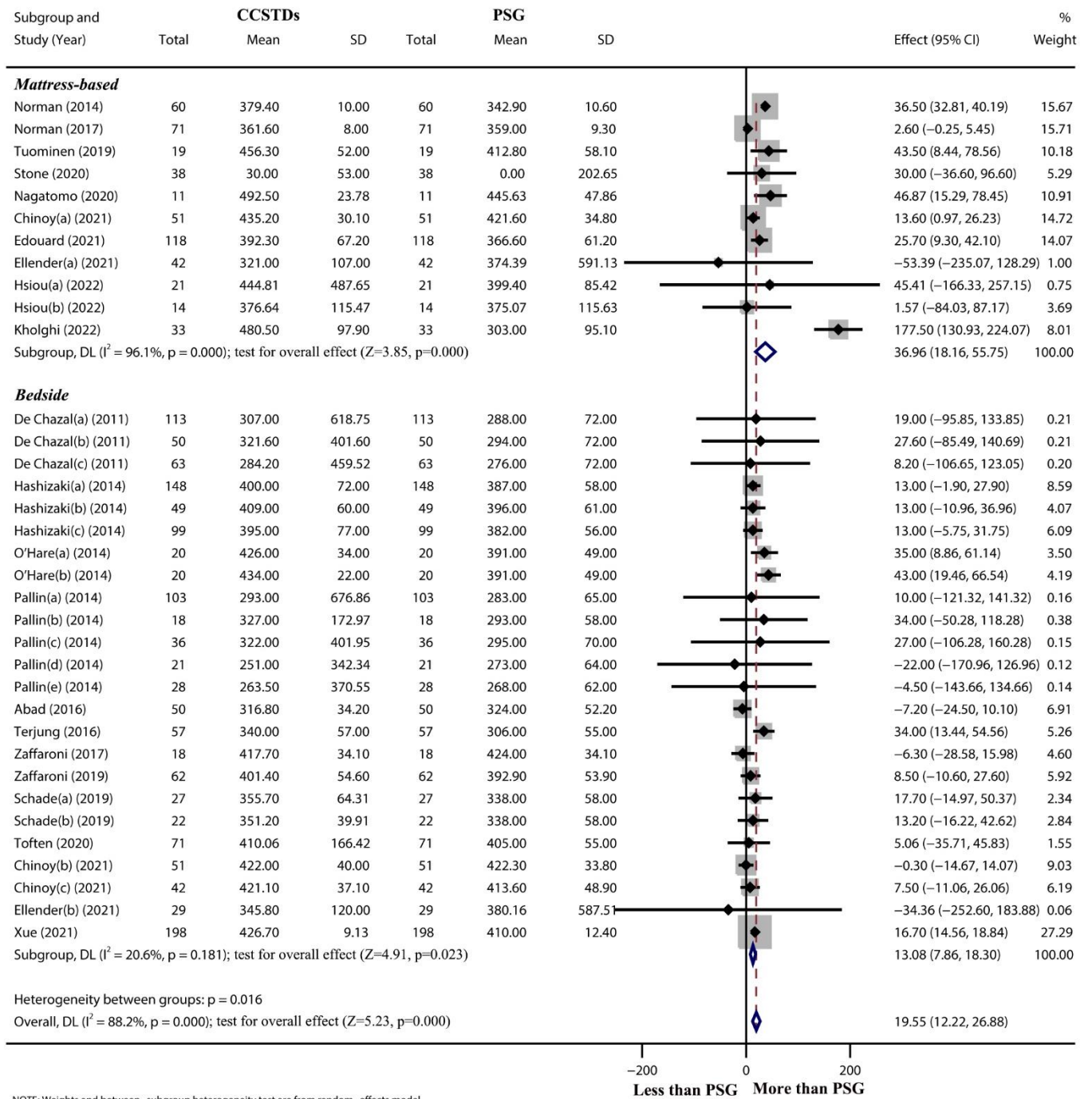


Figure S5. Forest plot meta-analyses for device types subgroup -TST (min).

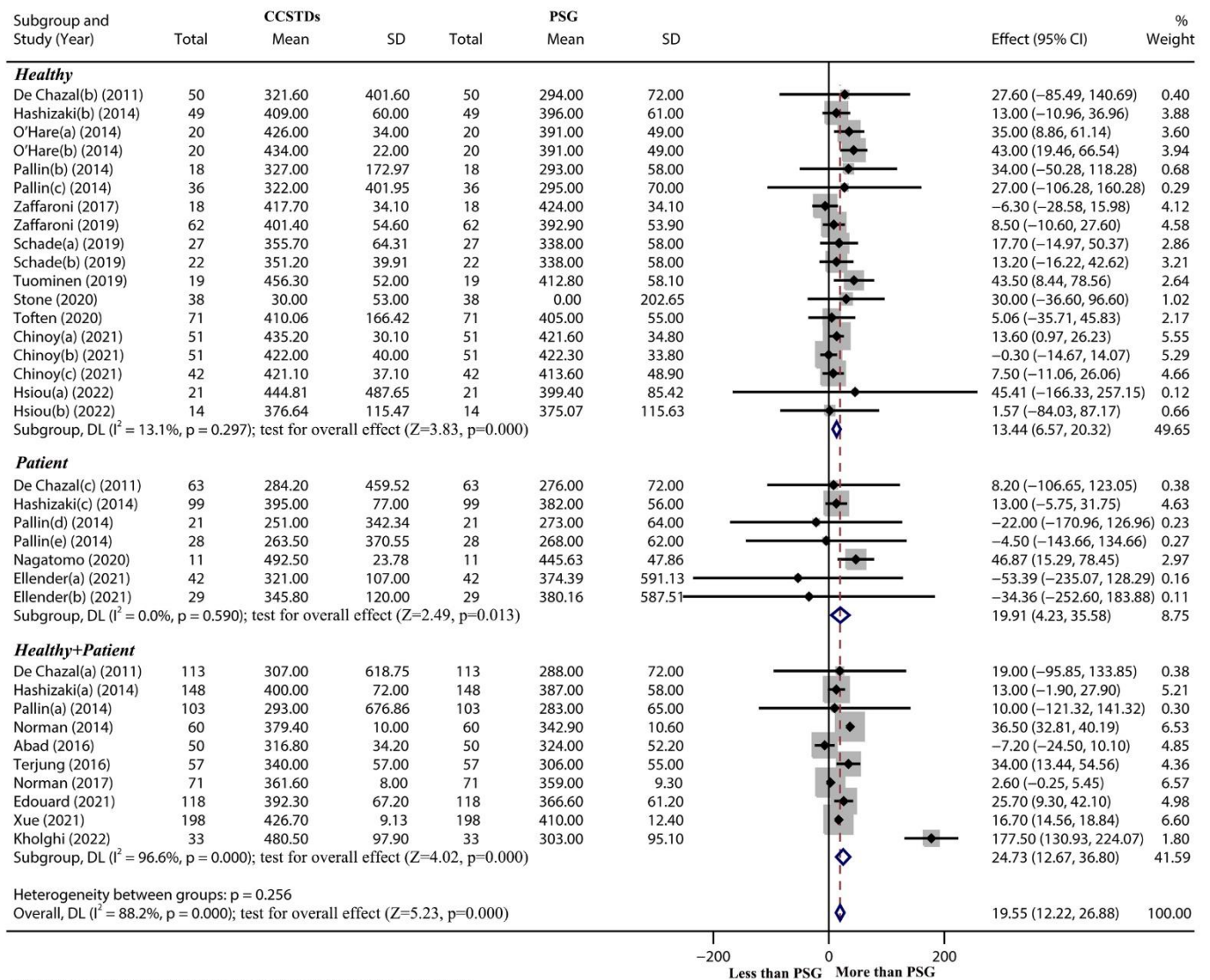


Figure S6. Forest plot meta-analyses for participant types subgroup - TST (min).

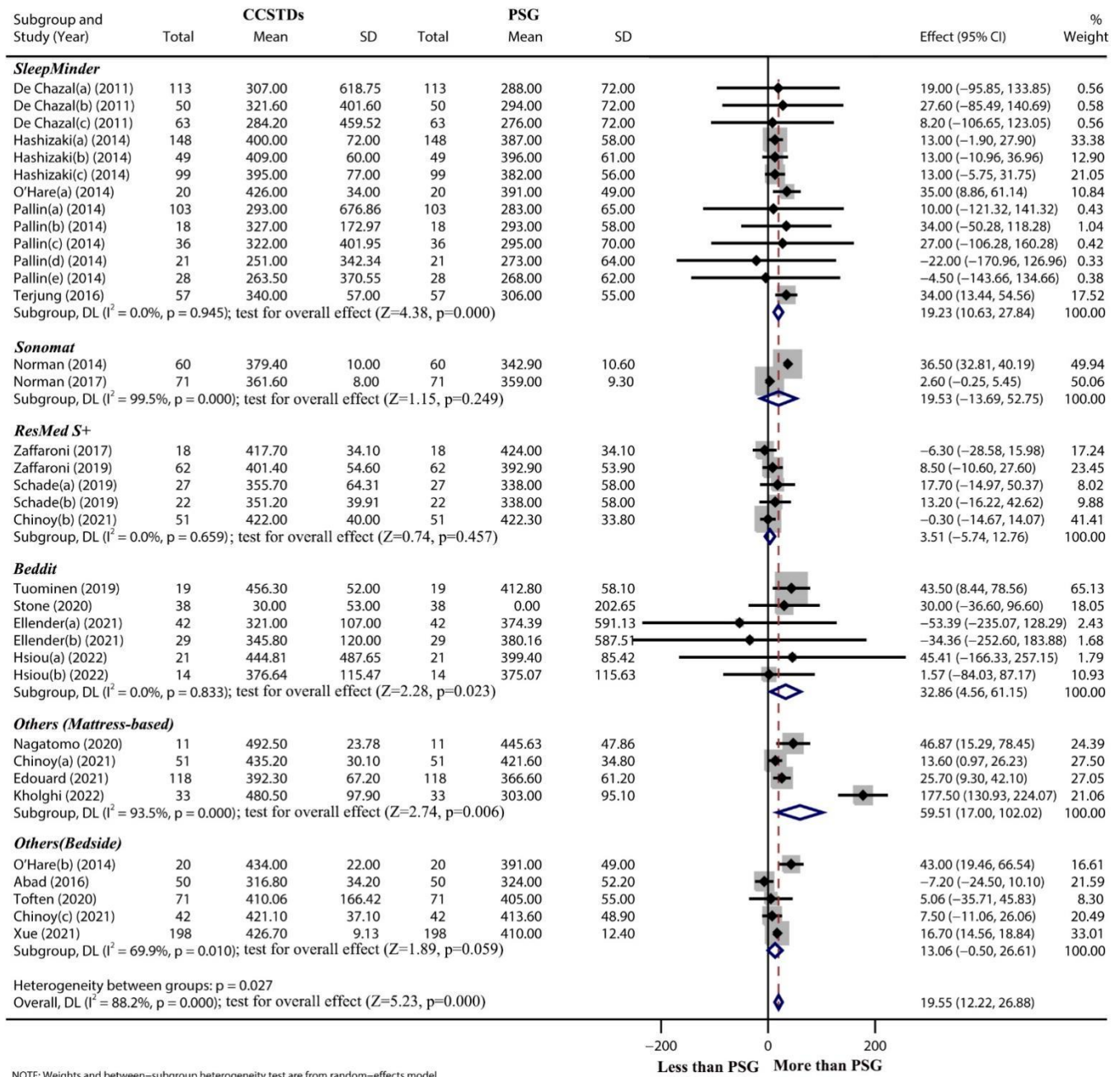


Figure S7. Forest plot meta-analyses for brands subgroup - TST (min).

- TST

As shown in Figures S4 to S7, compared CCSTDs with PSG, the subgroup analyses of sensors and brands revealed a nonsignificant difference of the piezoelectric sensor ($N=8$ studies; pooled mean=20.89 min, 95% CI -0.74 to 42.53; $P=.058$), infrared camera ($N=1$ study; pooled mean=-7.20 min, 95% CI -24.50 to 10.10; $P=.415$), Sonomat ($N=2$ studies; pooled mean=19.53 min, 95% CI -13.69 to 52.75; $P=.249$), ResMed S+ ($N=5$ studies; pooled mean=3.52 min, 95% CI -5.74 to 12.76; $P=.457$), and other brands of

bedside device (hereinafter referred to as “Others (Bedside)”) (N=5 studies; pooled mean=13.06 min, 95% CI -0.50 to 26.61; $P=.059$). However, bedside devices (hereinafter referred to as “Bedside”) (N=24 studies; pooled mean=19.55 min, 95% CI 12.22 to 26.88; $P<.001$), and healthy participants (hereinafter referred to as “Healthy”) (N=18 studies; pooled mean=13.44 min, 95% CI 6.57 to 20.32; $P<.01$) showed smaller mean differences in the respective subgroups. There was no significant heterogeneity in radiofrequency sensor ($I^2=0.0\%$; $p=.460$), Bedside ($I^2=20.6\%$; $p=.181$), patients ($I^2=0.0\%$; $p=.590$), Healthy ($I^2=13.1\%$; $p=.297$), SleepMinder ($I^2=0.0\%$; $p=.945$), ResMed S+ ($I^2=0.0\%$; $p=.659$), and Beddit ($I^2=0.0\%$; $p=.833$). Since only one study evaluated infrared camera, testing for heterogeneity was not relevant.

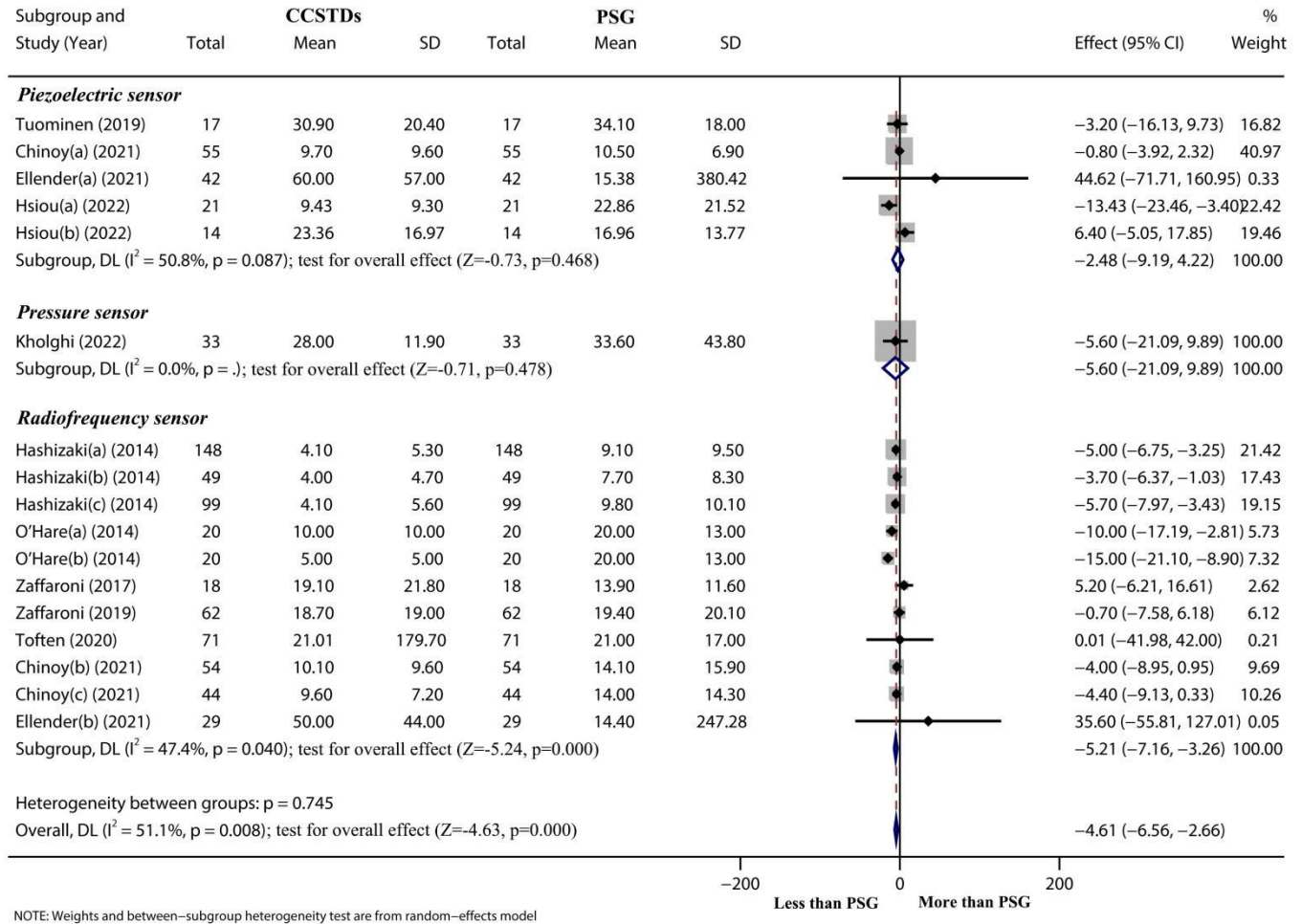


Figure S8. Forest plot meta-analyses for sensors subgroup – SOL (min).

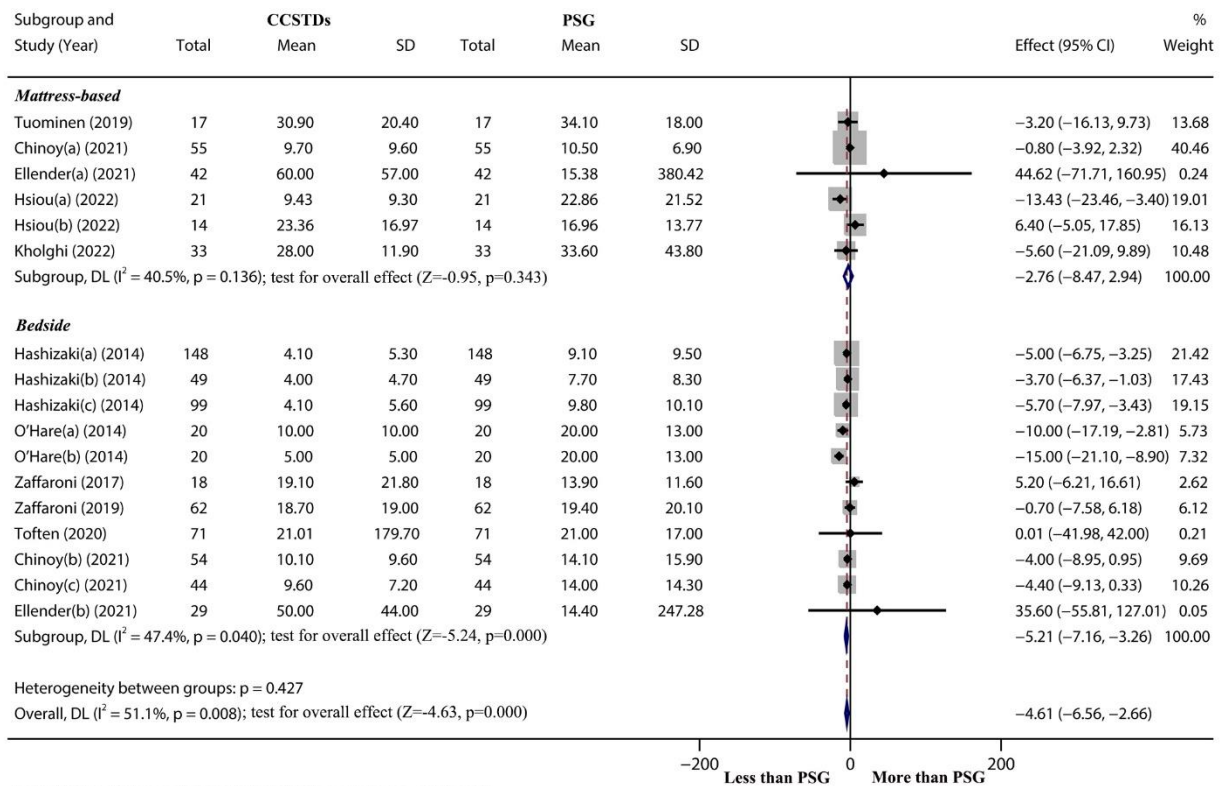


Figure S9. Forest plot meta-analyses for device types subgroup – SOL (min).

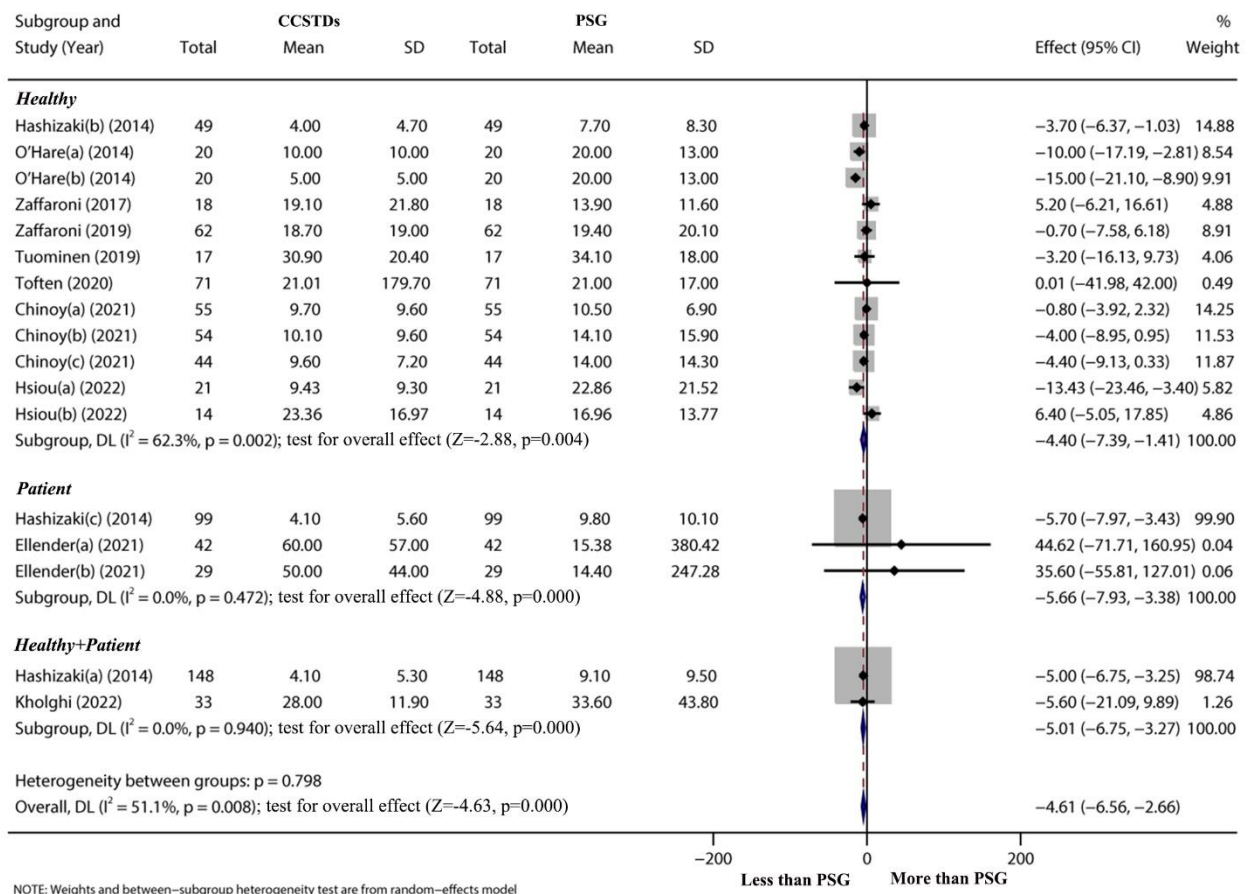


Figure S10. Forest plot meta-analyses for participant types subgroup – SOL (min).

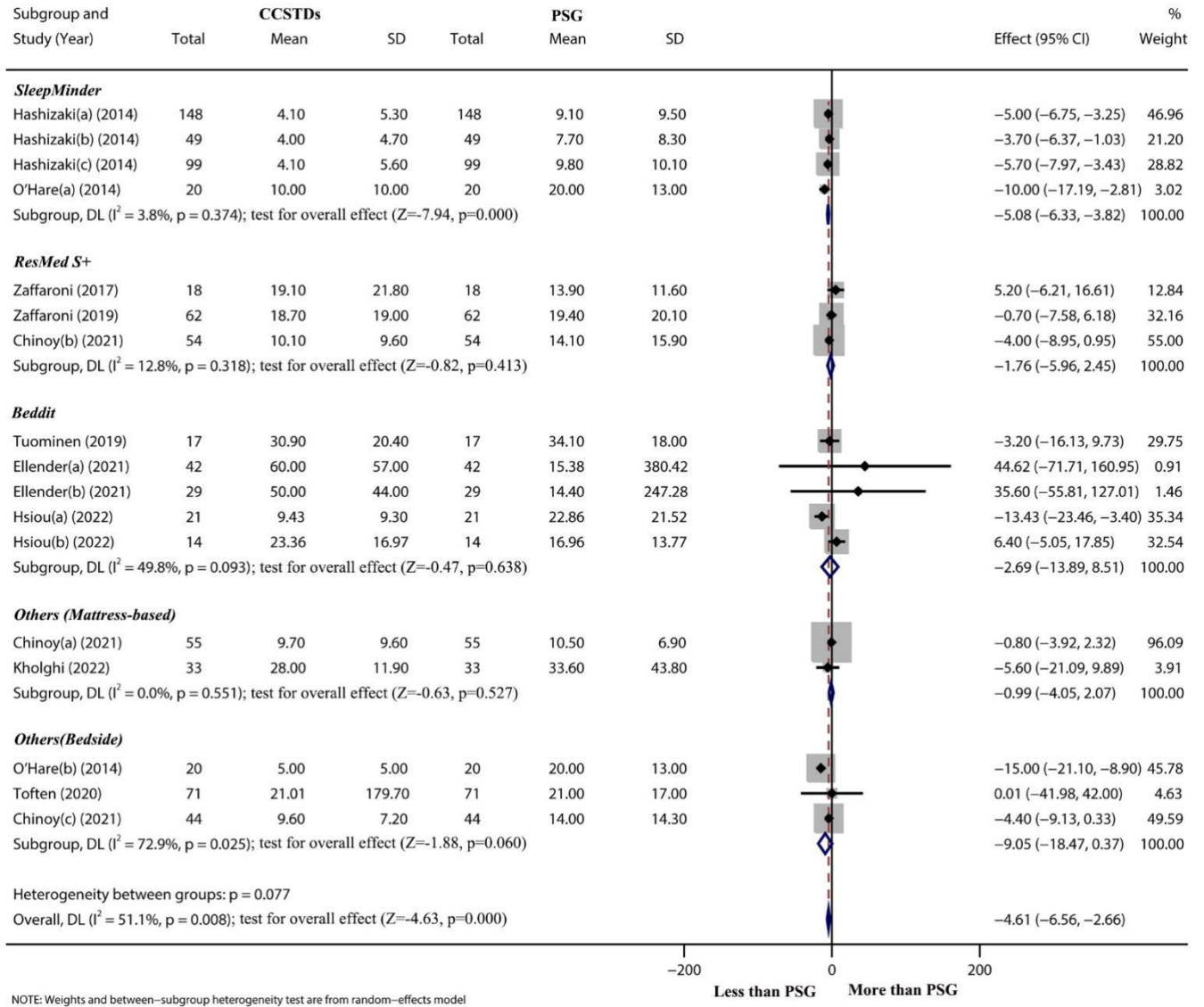


Figure S11. Forest plot meta-analyses for brands subgroup – SOL (min).

- SOL

Compared with PSG, the pooled estimate of effect size (see Figures S8 to S11) revealed a significant underestimation of radiofrequency sensor (N=11 studies; pooled mean=-5.21 min, 95% CI -7.16 to -3.26; $P < .001$), Bedside (N=11 studies; pooled mean=-4.61 min, 95% CI -6.56 to -2.66; $P < .001$), Healthy (N=12 studies; pooled mean=-4.4 min, 95% CI -7.39 to -1.41; $P < .01$), and SleepMinder (N=4 studies; pooled mean=-5.08 min, 95% CI -6.33 to -3.82; $P < .001$), while nonsignificant differences are shown in the estimation of piezoelectric sensor (N=5 studies; pooled mean=-2.48 min, 95% CI -9.19 to 4.22; $P < .468$), pressure sensor (N=1 study; pooled mean=-5.60 min, 95% CI -21.09 to 9.89; $P < .478$), mattress-based devices (hereinafter referred to as “Mattress-based”) (N=6

studies; pooled mean=-2.76 min, 95% CI -8.47 to 2.94; $P=.343$), patient participants (hereinafter referred to as “Patient”) (N=3 studies; pooled mean=-5.66 min, 95% CI -7.93 to 3.38; $P=.472$), both healthy and patient participants (hereinafter referred to as “Healthy+ Patient”) (N=2 studies; pooled mean=-5.01 min, 95% CI -6.75 to 3.27; $P=.478$), ResMed S+ (N=3 studies; pooled mean =-1.76 min, 95% CI -5.96 to 2.45; $P=.413$), Beddit (N=5 studies; pooled mean=-2.69 min, 95% CI -13.89 to 8.51; $P=.638$), other brands of mattress device (hereinafter referred to as “Others (Mattress-based)”) (N=2 studies; pooled mean=-0.99 min, 95% CI -4.05 to 2.08; $P=.527$), and Others (Bedside) (N=3 studies; pooled mean=-9.05 min, 95% CI -18.47 to 0.37; $P=.060$). There was no significant heterogeneity in Mattress-Based ($I^2=40.5\%$; $p=.136$), Patient ($I^2=0.0\%$; $p=.472$), Healthy+Patient ($I^2=0.0\%$; $p=.940$), SleepMinder ($I^2=3.8\%$; $p=.374$), ResMed S+ ($I^2=12.8\%$; $p=.318$), and Others (Mattress-based) ($I^2=0.0\%$; $p=.551$). Since only one study evaluated pressure sensor, testing for heterogeneity was not relevant.

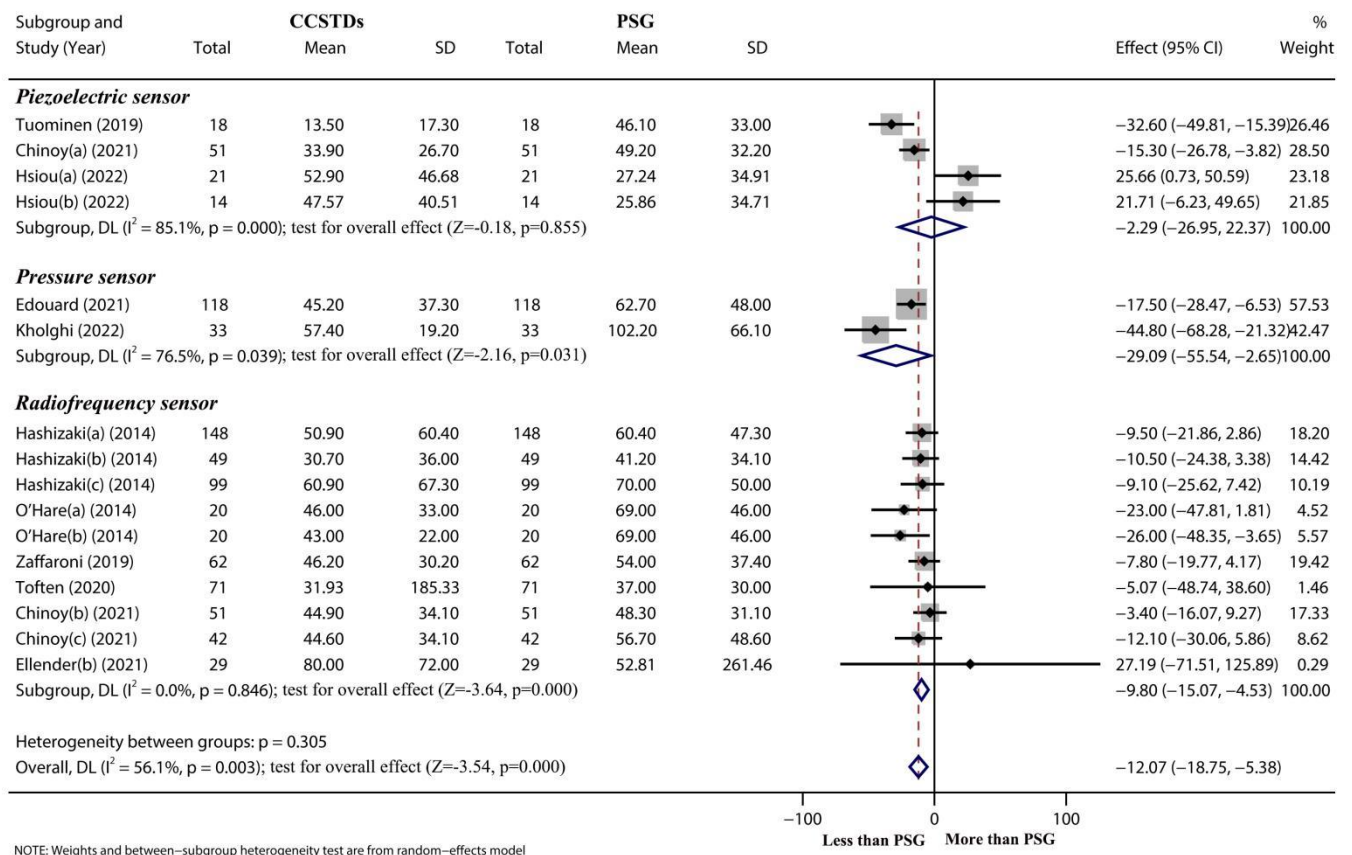
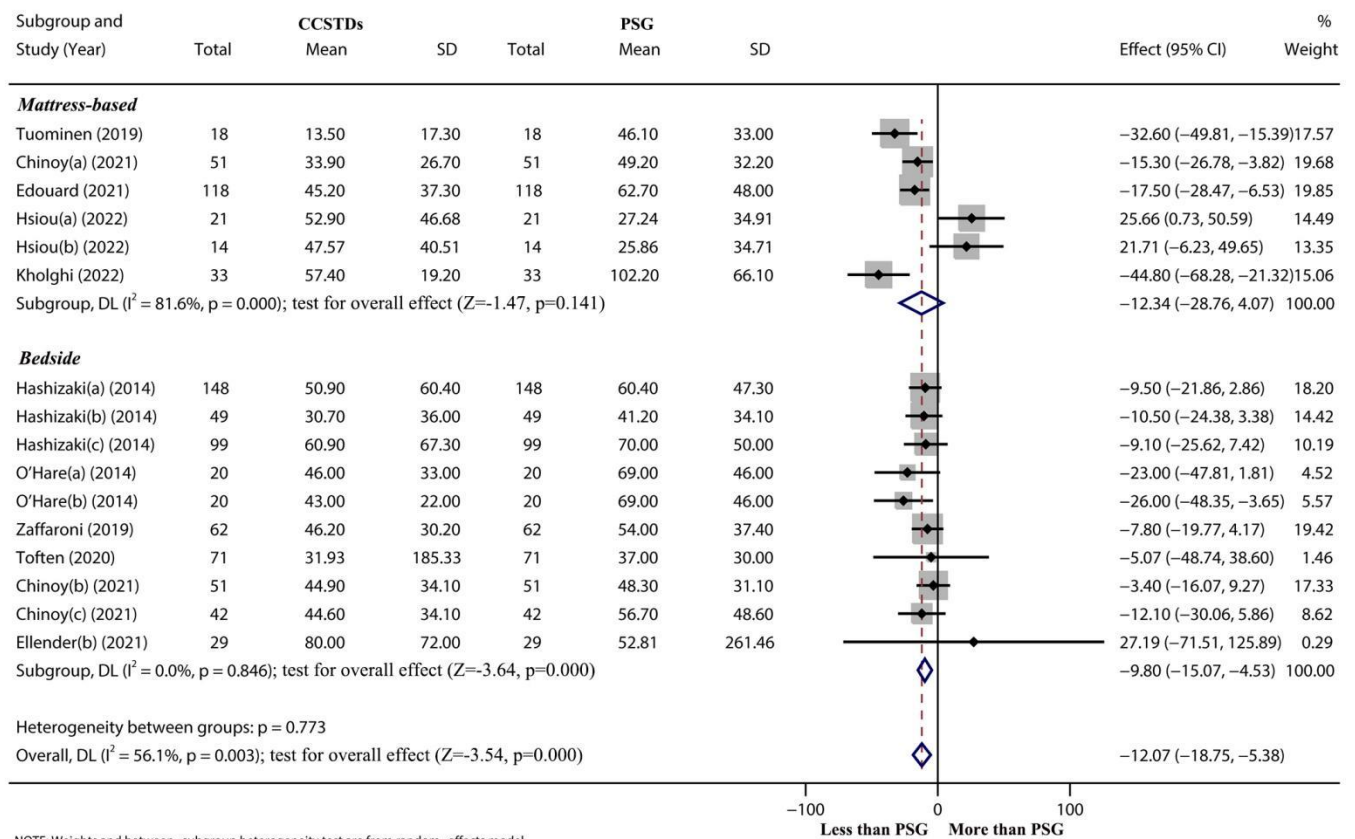


Figure S12. Forest plot meta-analyses for sensors subgroup -WASO (min).



NOTE: Weights and between-subgroup heterogeneity test are from random-effects model

Figure S13. Forest plot meta-analyses for device types subgroup -WASO (min).

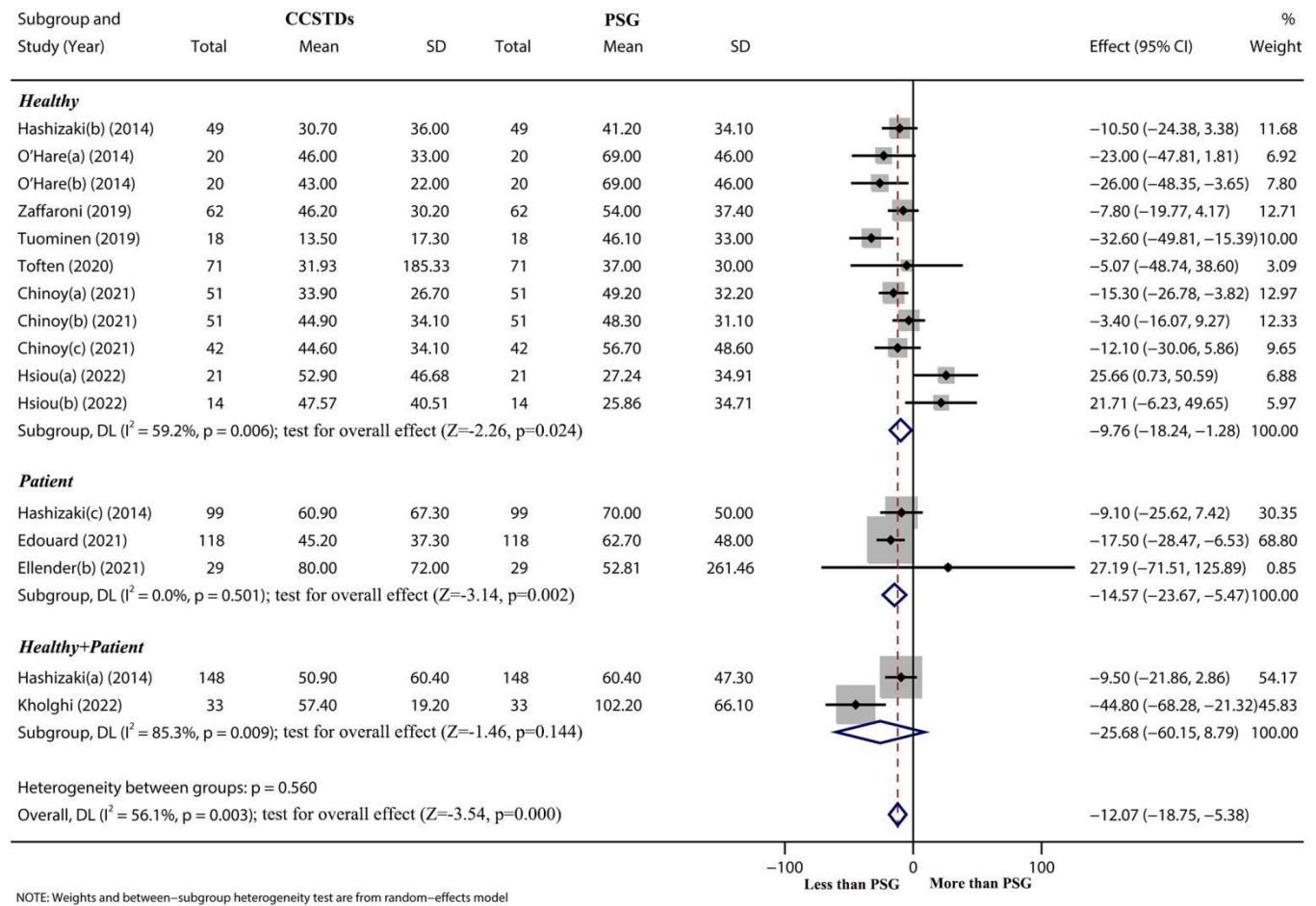


Figure S14. Forest plot meta-analyses for participants type subgroup – WASO (min).

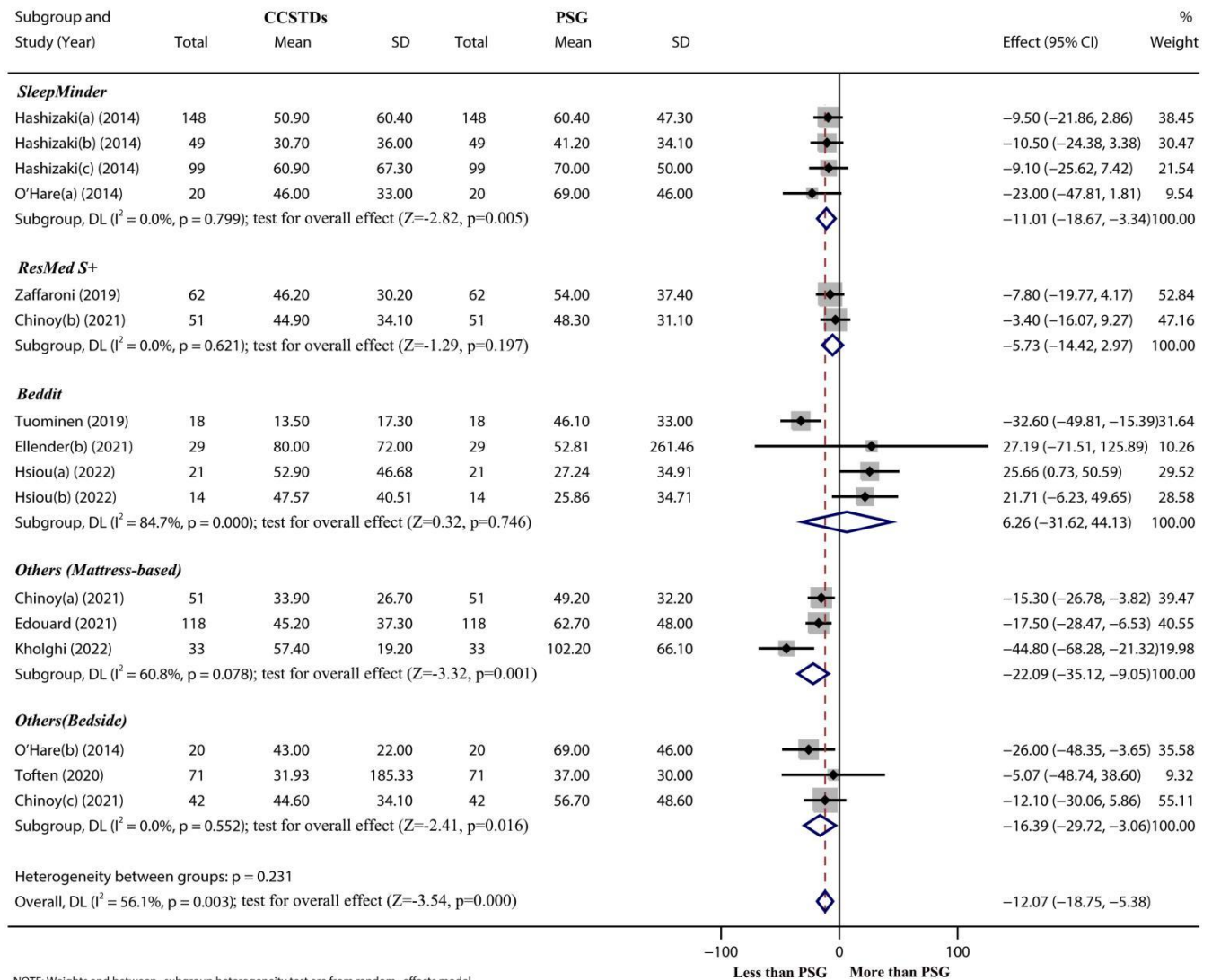


Figure S15. Forest plot meta-analyses for brands subgroup – WASO (min).

- **WASO**

The subgroup analyses in Figures S12 to S15 revealed general significant underestimation compared to PSG, but piezoelectric sensor (N=4 studies; pooled mean=-2.29 min, 95% CI -26.95 to 22.37; $P=.855$), Mattress-Based (N=6 studies; pooled mean=-12.34 min, 95% CI -28.76 to 4.07; $P=.141$), Healthy+Patient (N=2 studies; pooled mean=-25.68 min, 95% CI -60.15 to 8.79; $P=.144$), ResMed S+ (N=2 studies; pooled mean=-5.73 min, 95% CI -14.42 to 2.97; $P=.197$), and Beddit (N=4 studies; pooled mean=6.26 min, 95% CI -31.62 to 44.13; $P=.746$) showed a nonsignificant difference. There was no significant heterogeneity in Radiofrequency sensor ($I^2=0.0\%$; $p=.846$), Bedside ($I^2=0.0\%$; $p=.846$), Patients ($I^2=0.0\%$; $p=.501$), SleepMinder ($I^2=0.0\%$; $p=.799$), ResMed S+ ($I^2=0.0\%$; $p=.621$), and Others (Bedside) ($I^2=0.0\%$; $p=0.552$).

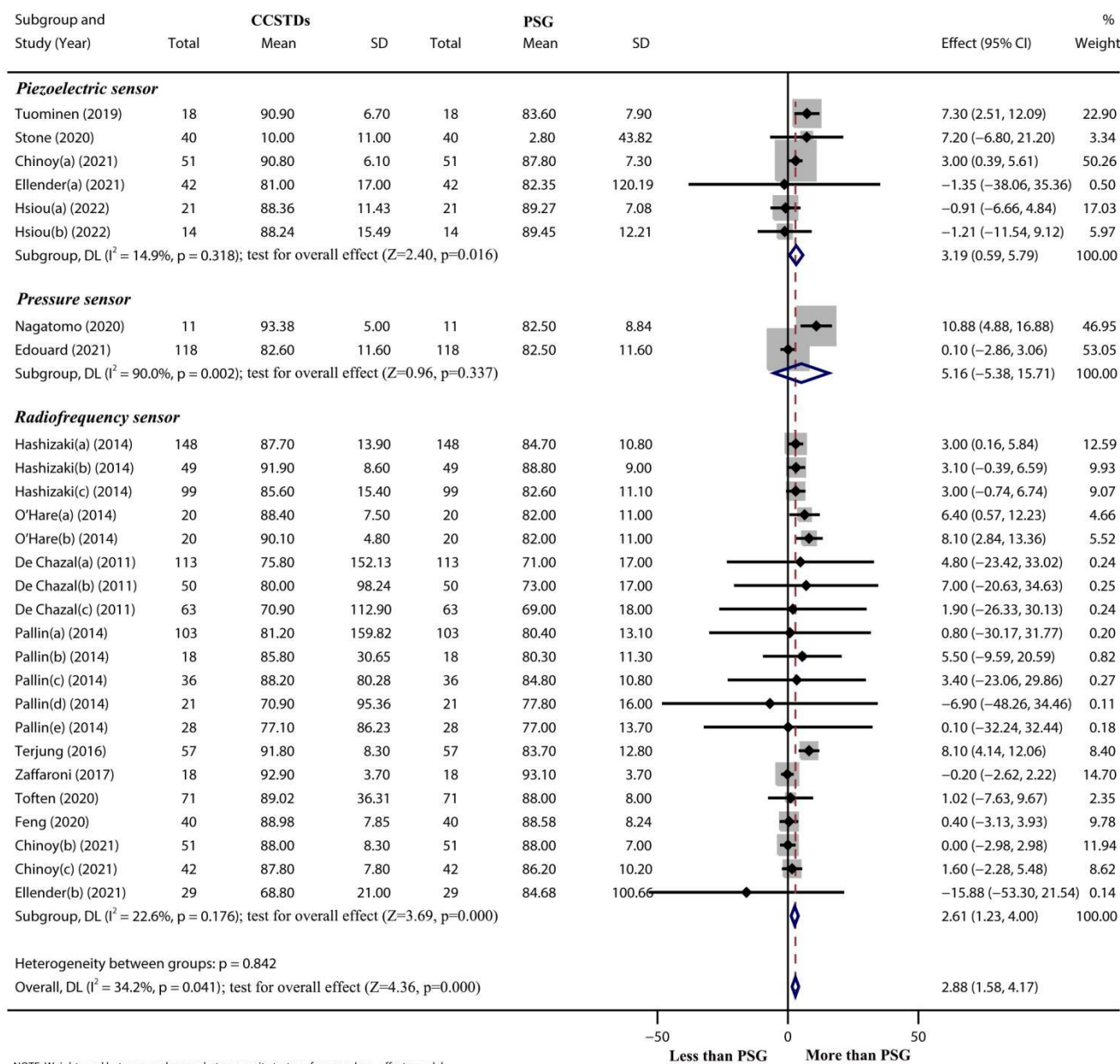


Figure S16. Forest plot meta-analyses for sensors subgroup - SE (%).

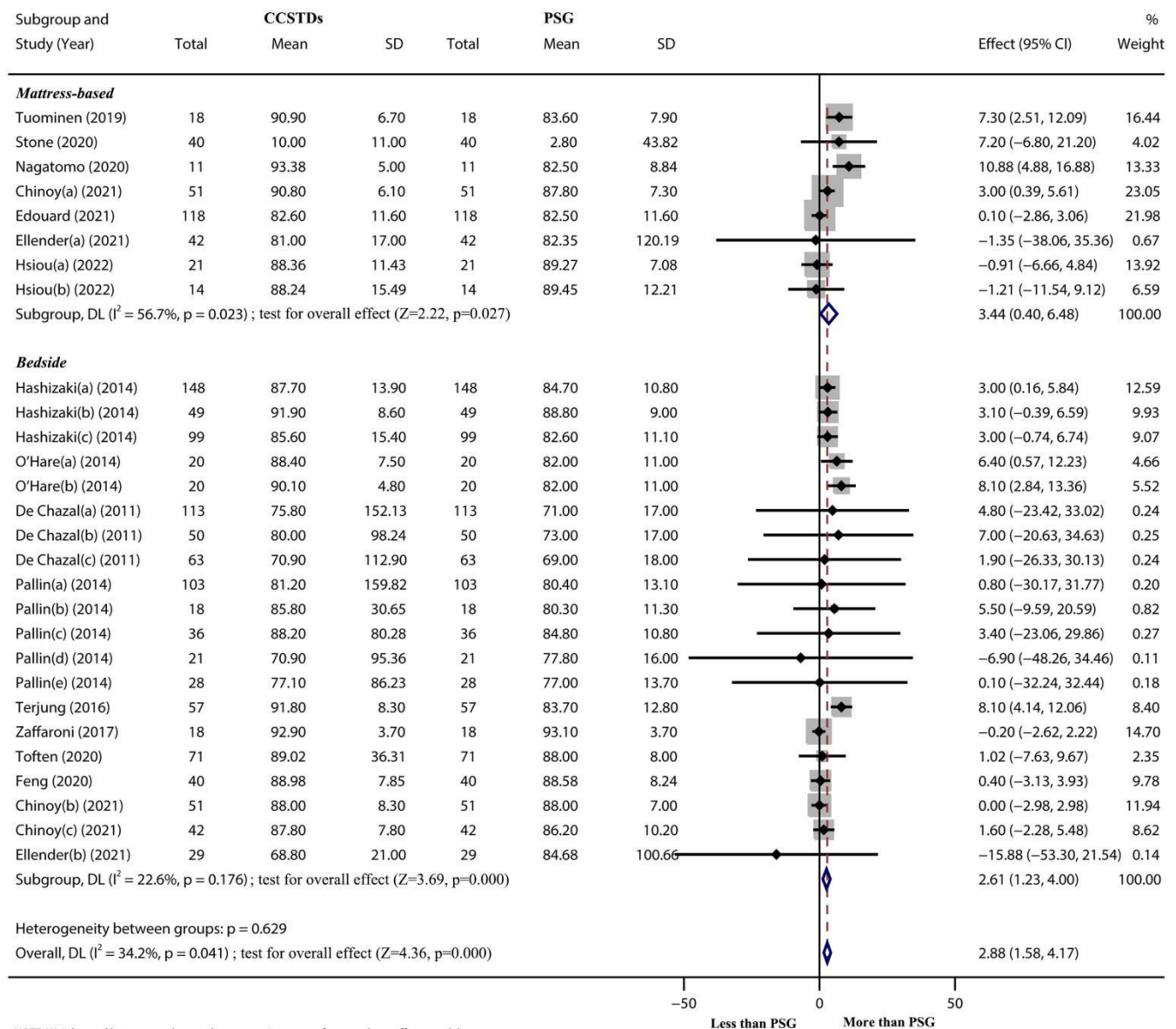


Figure S17. Forest plot meta-analyses for device types subgroup - SE (%)

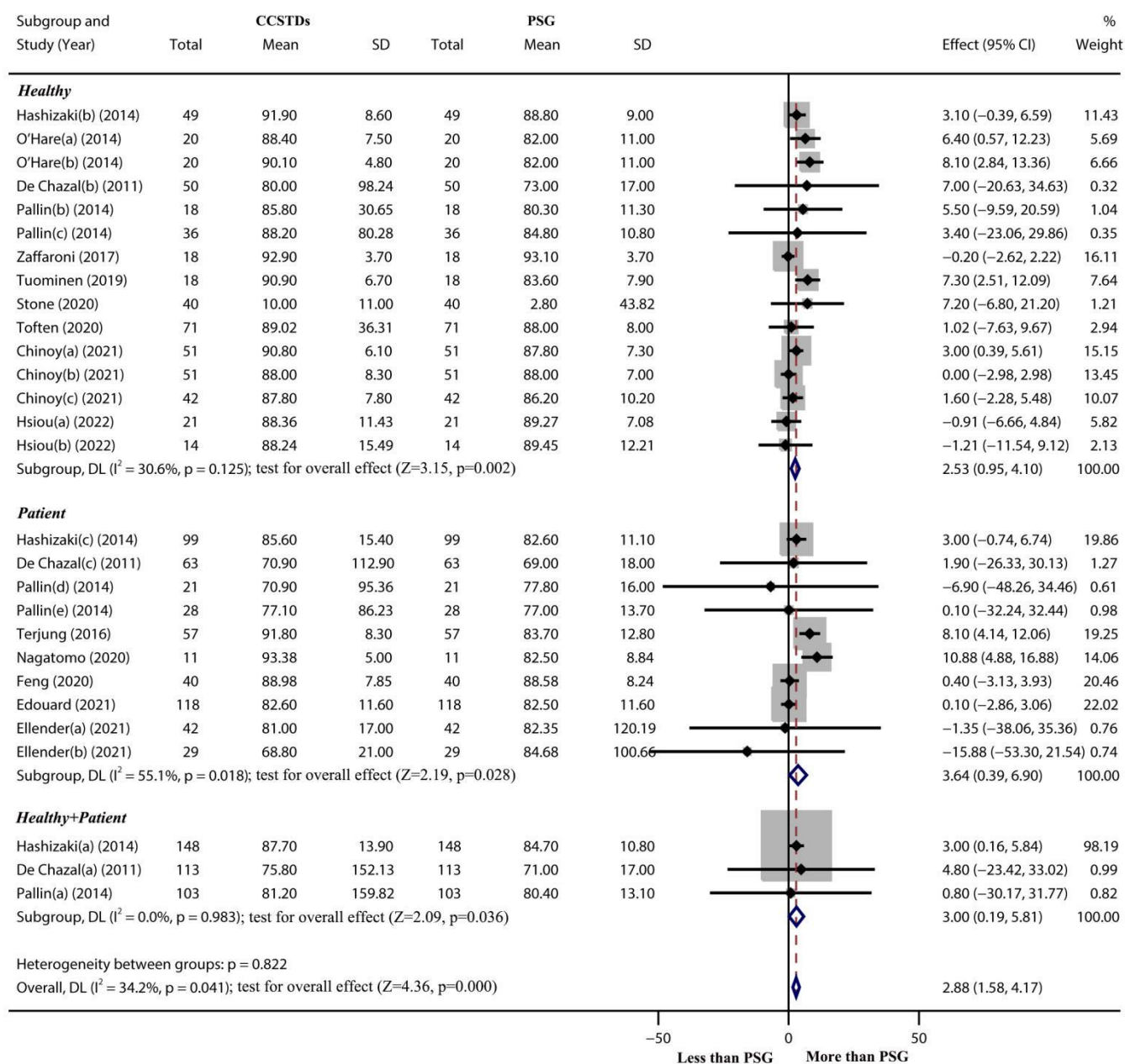


Figure S18. Forest plot meta-analyses for participant types subgroup - SE (%).

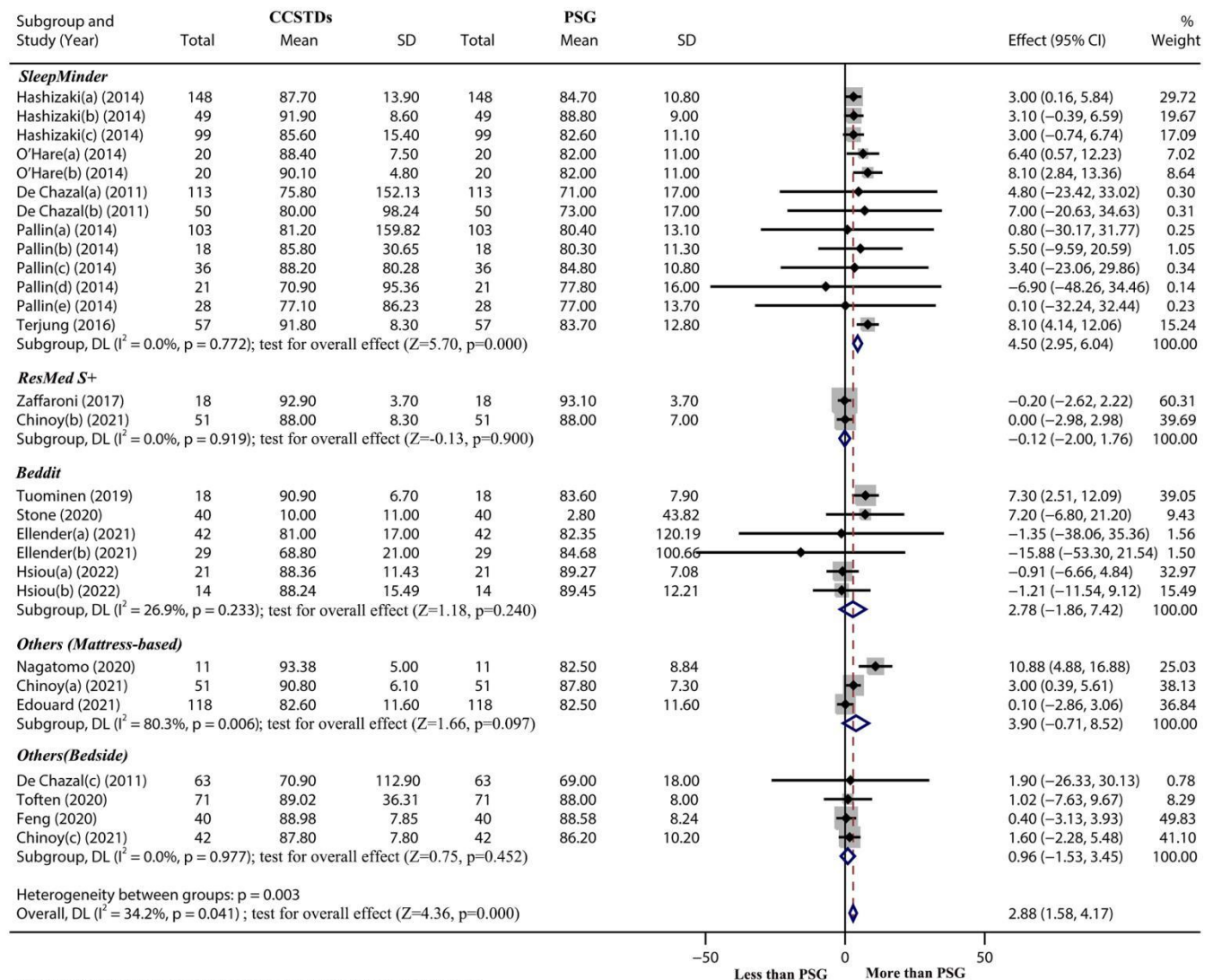


Figure S19. Forest plot meta-analyses for brands subgroup - SE (%).

- SE

Analysis of three subgroups in Figures S16 to S19 revealed significant overestimation except for pressure sensor (N=2 studies; pooled mean=5.16 min, 95% CI -5.38 to 15.71; $P=.337$) compared to PSG. The results of the subgroup analyses (see Figure S19) for the brand of devices showed no significant difference except for SleepMinder (N=13 studies; pooled mean=4.50 min, 95% CI 2.95 to 6.04; $P<.001$) which was a significant difference. The significant heterogeneity was detected only in pressure sensor ($I^2=90.0\%$; $P=.002$), Mattress-Based ($I^2=56.7\%$; $P=.023$), Patient ($I^2=55.1\%$; $p=.018$), and Others (Mattress-based) ($I^2=80.3\%$; $p=.006$).

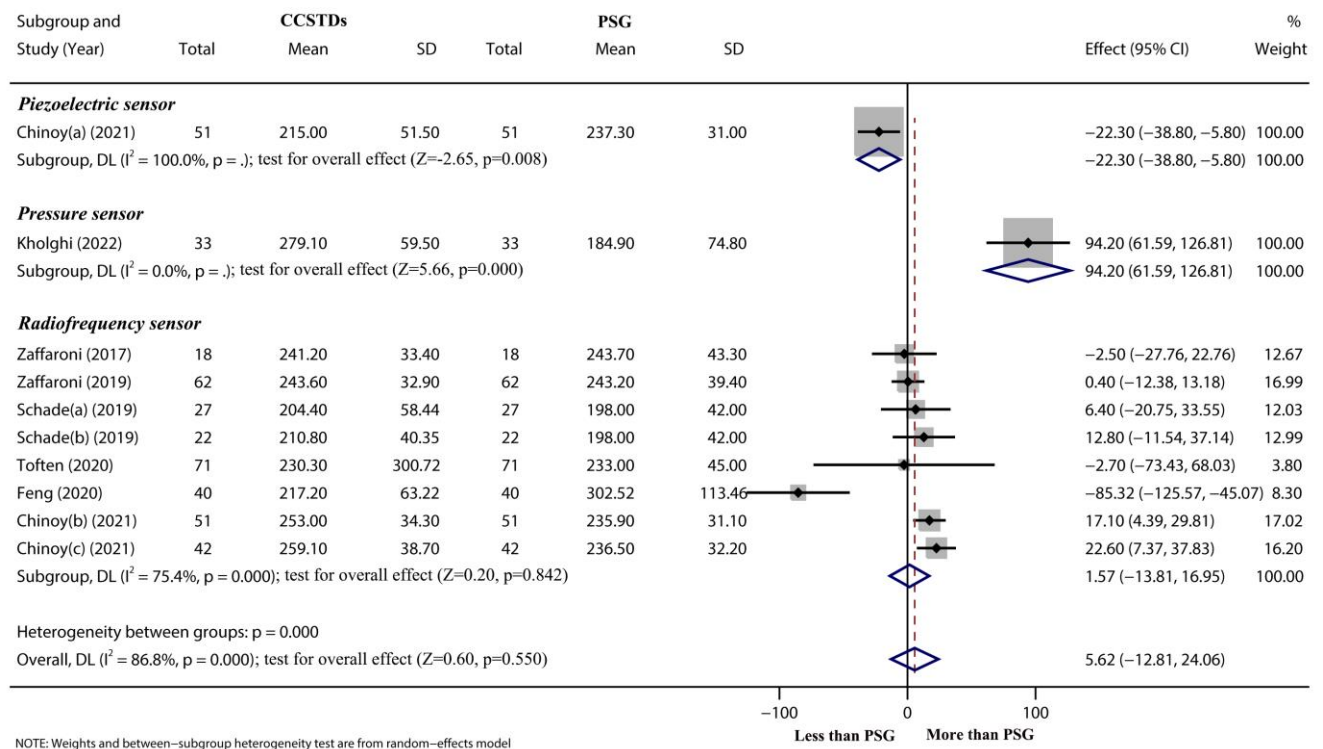


Figure S20. Forest plot meta-analyses for sensors subgroup - light sleep(min).

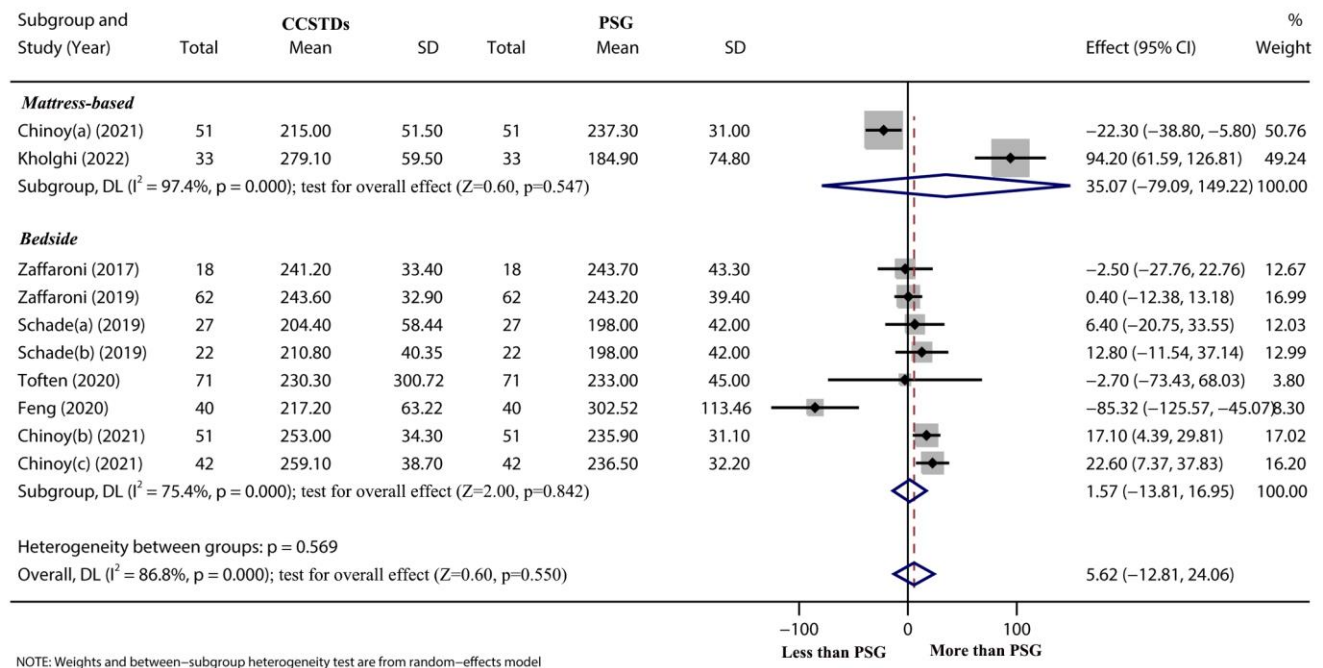


Figure S21. Forest plot meta-analyses for devices type subgroup - light sleep(min).

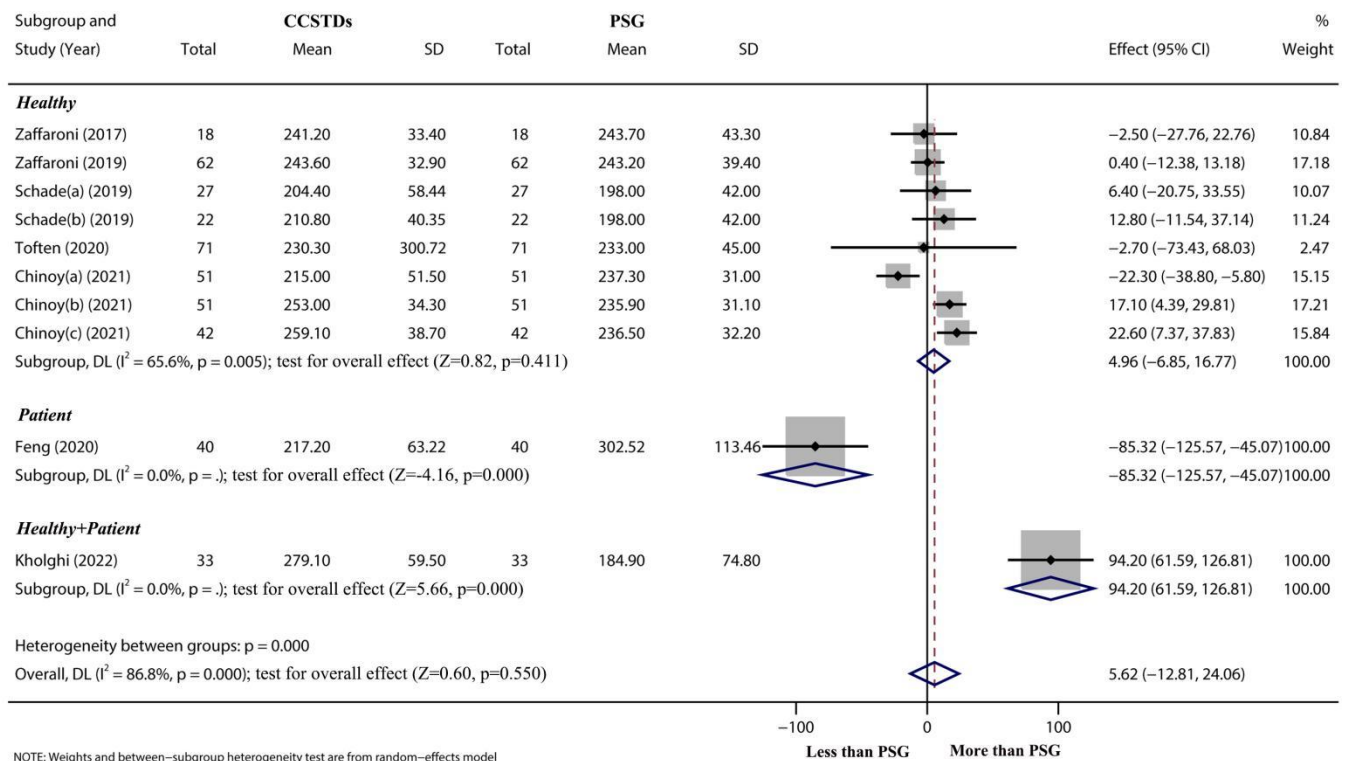


Figure S22. Forest plot meta-analyses for participant types subgroup - light sleep(min).

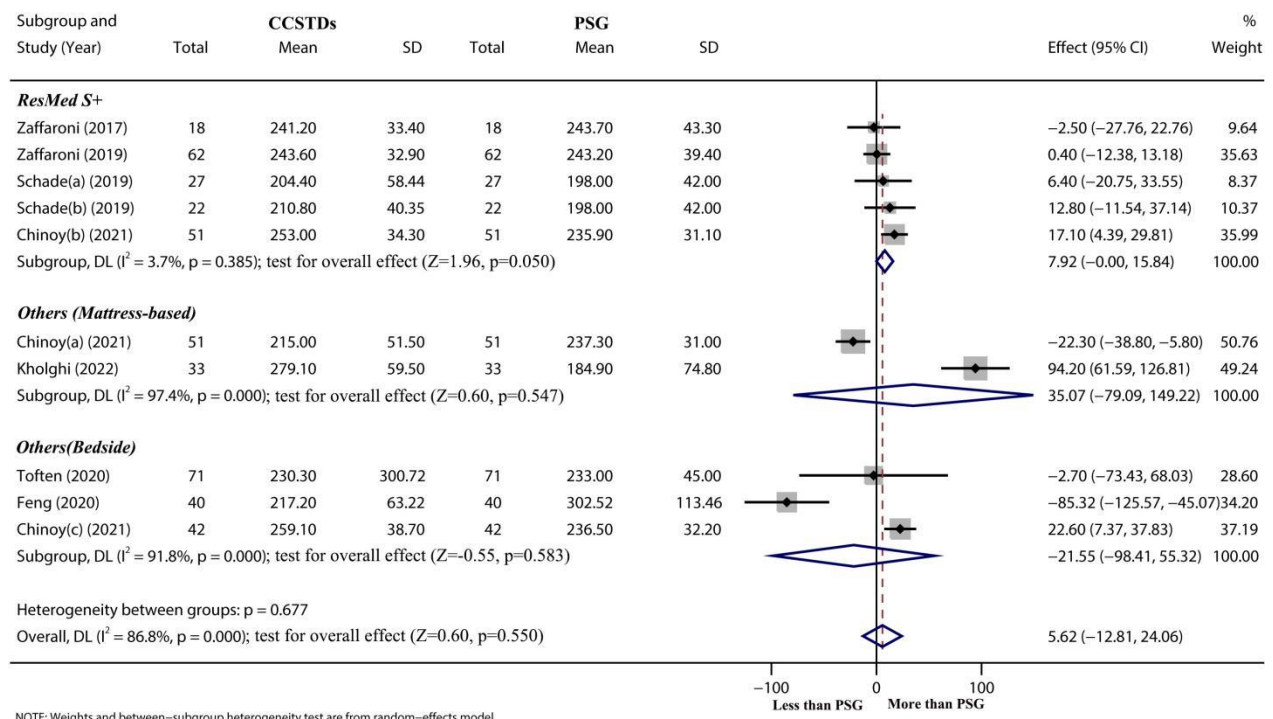


Figure S23. Forest plot meta-analyses for brands subgroup - light sleep(min).

- **Light Sleep**

Compared with PSG, the pooled estimate of effect size in Figures S20 to S23 revealed the following: nonsignificant difference in the estimation of radiofrequency sensor (n=8 studies; pooled mean=1.57 min, 95% CI -13.81 to 16.95; P=.842), Mattress-Based (n=2 studies; pooled mean=35.07 min, 95% CI -79.09 to 149.22; P=.547), Bedside (n=8 studies; pooled mean=1.57 min, 95% CI -13.81 to 16.95; P=.842), Healthy (n=8 studies; pooled mean=4.96 min, 95% CI -6.86 to 16.78; P=.404), and the subgroup of brands; significant underestimation of piezoelectric sensor (n=1 study; pooled mean=-22.30 min, 95% CI -38.80 to -5.80; P<.01), Patient (n=1 study; pooled mean=-85.32 min, 95% CI -125.57 to -45.07; P<.001); significant overestimation of pressure sensor (n=1 study; pooled mean =94.20 min, 95% CI 61.59 to 126.81; P<.001), Healthy+Patient (n=1 study; pooled mean =94.20 min, 95% CI 61.59 to 126.81; P<.001). The nonsignificant heterogeneity was only detected in ResMed S+ ($I^2=3.7\%$; $p=.385$). Since only one study evaluated piezoelectric sensor, pressure sensor, Patient and Healthy+Patient, testing for heterogeneity was not relevant.

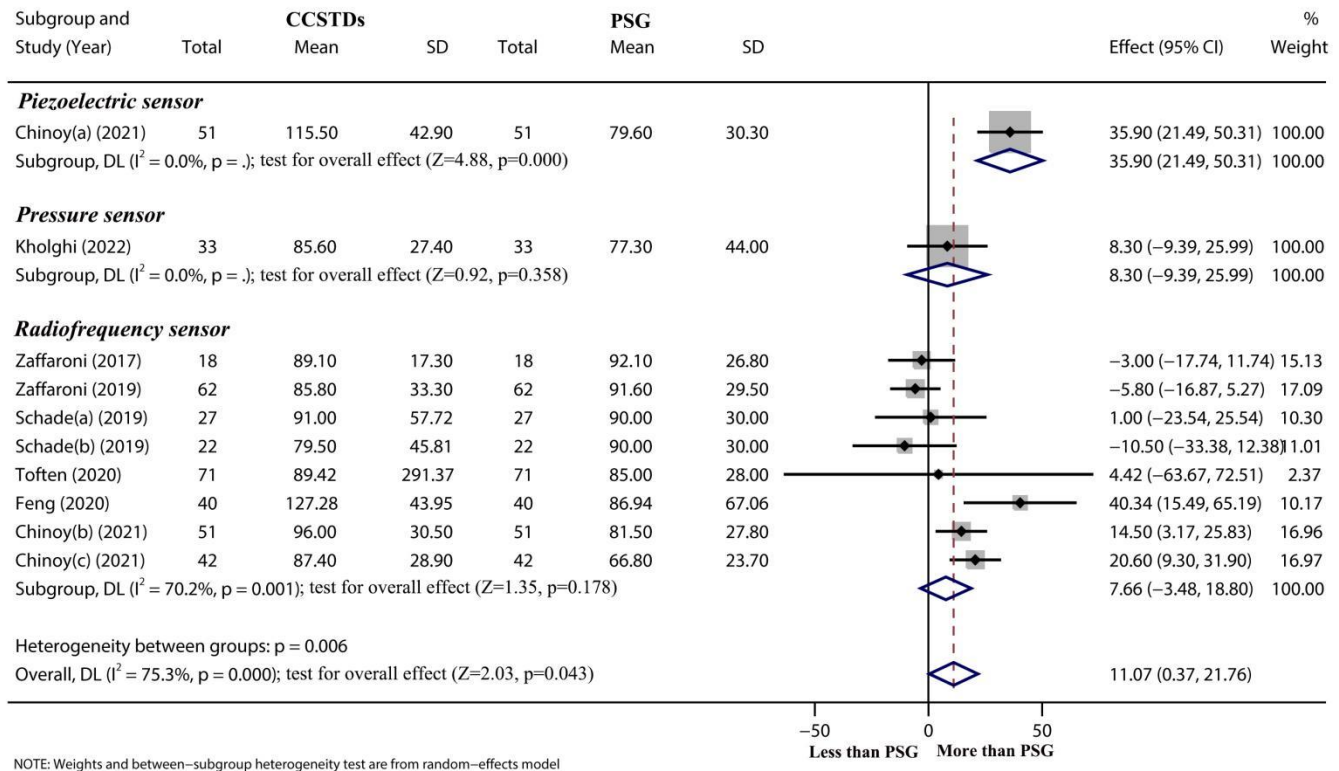


Figure S24. Forest plot meta-analyses for sensors subgroup - deep sleep(min).

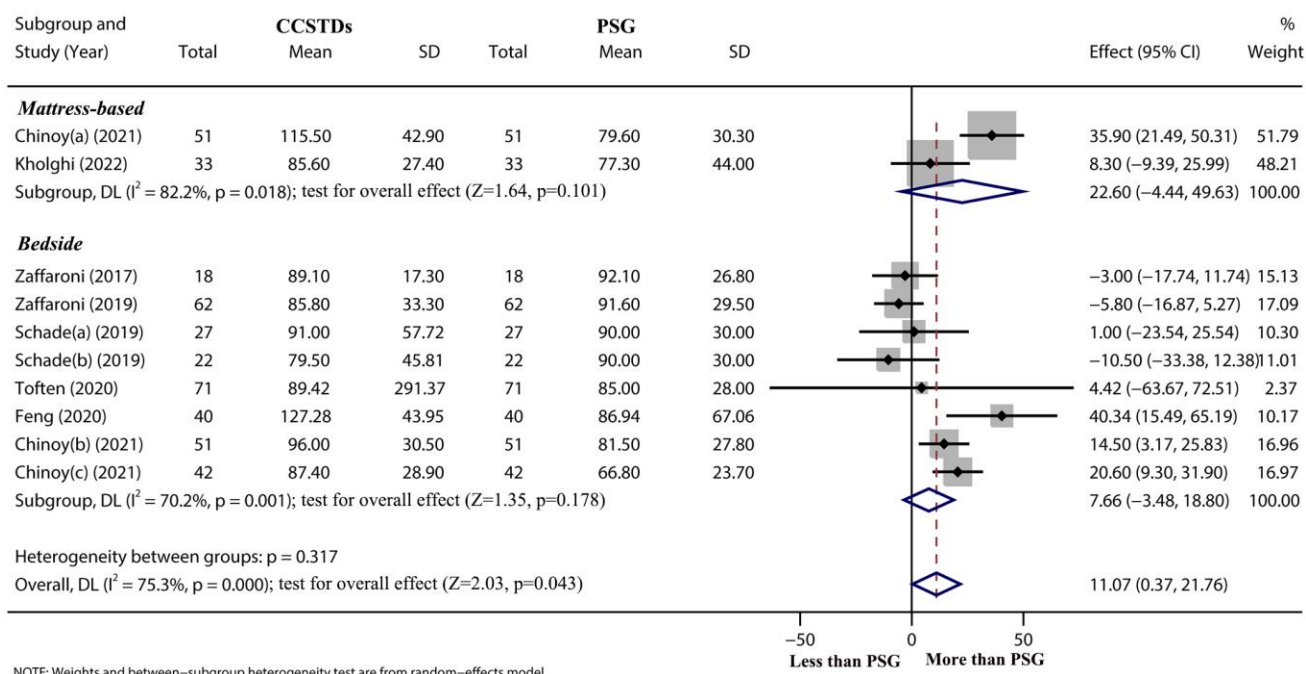


Figure S25. Forest plot meta-analyses for device types subgroup - deep sleep(min).

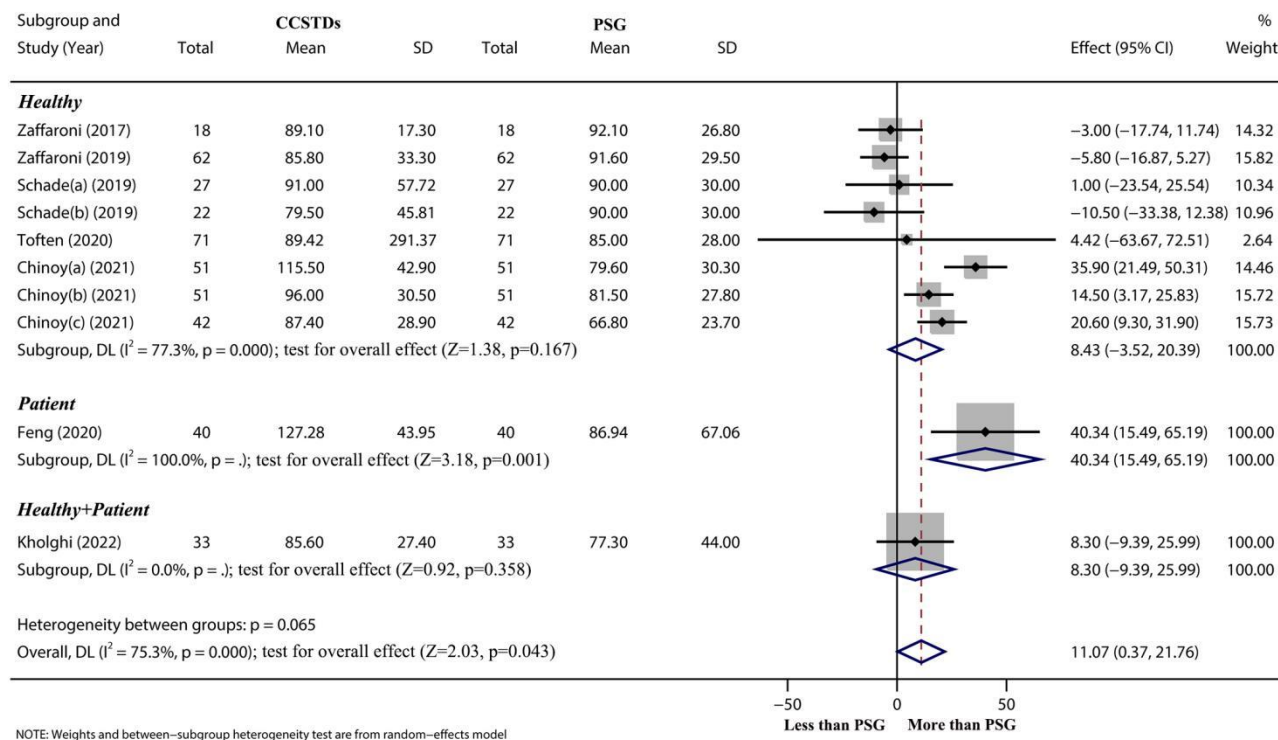


Figure S26. Forest plot meta-analyses for participant types subgroup - deep sleep(min).

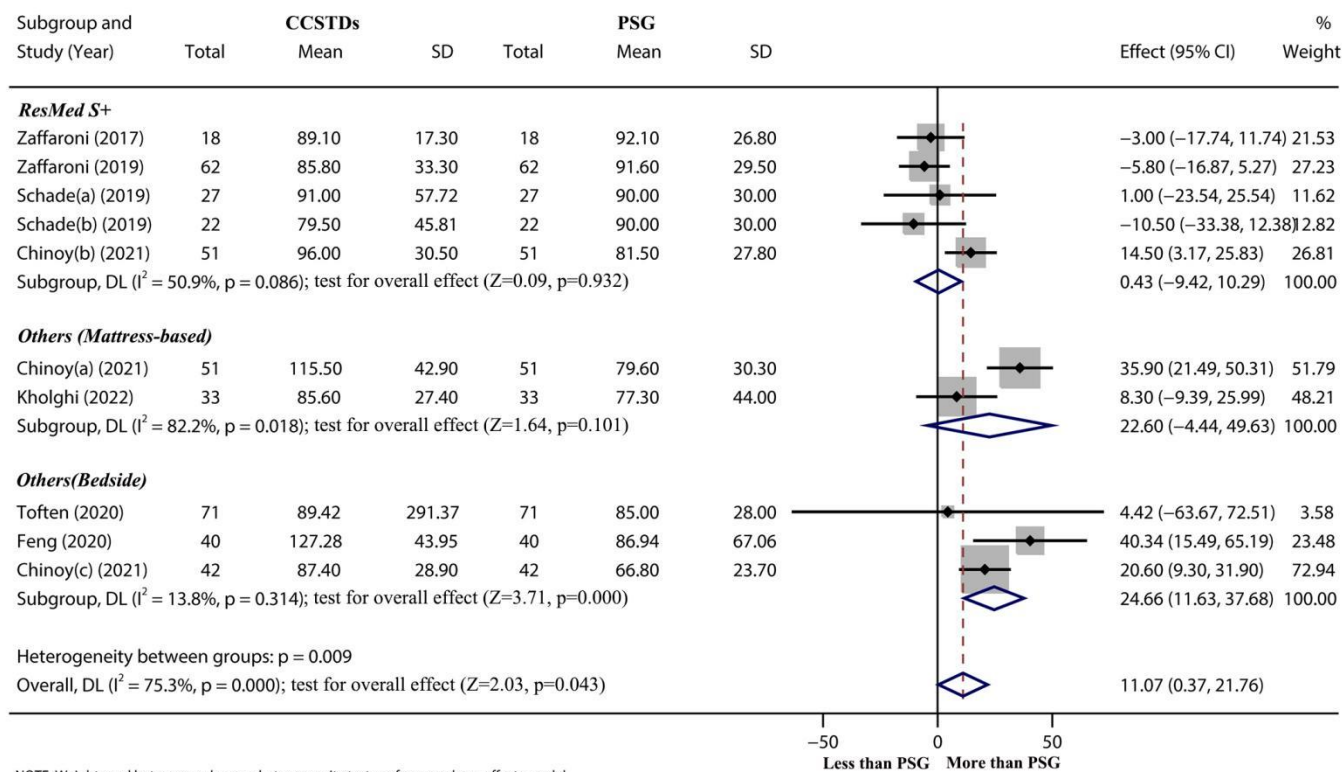


Figure S27. Forest plot meta-analyses for brands subgroup - deep sleep(min).

• Deep Sleep

Compared with PSG, the pooled estimate of effect size in Figures S24 to S27 revealed no significant difference in pressure sensor ($n=1$ study; pooled mean=8.30 min, 95% CI -9.39 to 25.99; $P=.358$), radiofrequency sensor ($n=8$ studies; pooled mean=7.66 min, 95% CI -3.48 to 18.80; $P=.178$), Healthy ($n=8$ studies; pooled mean=8.43 min, 95% CI -3.52 to 20.39; $P=.167$), Healthy+Patients ($n=1$ study; pooled mean=8.30min, 95% CI -9.39 to 25.99; $P=.358$), ResMed S+ ($n=5$ studies; pooled mean=0.43 min, 95% CI -9.43 to 10.29; $P=.932$), Others (Mattress-based) ($n=2$ studies; pooled mean=22.60 min, 95% CI -4.44 to 49.63; $P=.101$), and the subgroup of type of device. The significant overestimation was detected in piezoelectric sensor ($n=1$ study; pooled mean=35.9 min, 95% CI 21.49 to 50.31; $P<.001$), Patient ($n=1$ study; pooled mean=40.34 min, 95% CI 15.49 to 65.19; $P<.001$), and Others (Bedside) ($n=3$ studies; pooled mean=24.66 min, 95% CI 11.64 to 37.68; $P<.001$). There was no significant heterogeneity only in Others (Bedside) ($I^2=13.8\%$; $P=.314$). Since only one study evaluated piezoelectric sensor, pressure sensor, Patient, and Healthy+Patient, testing for heterogeneity was not relevant.

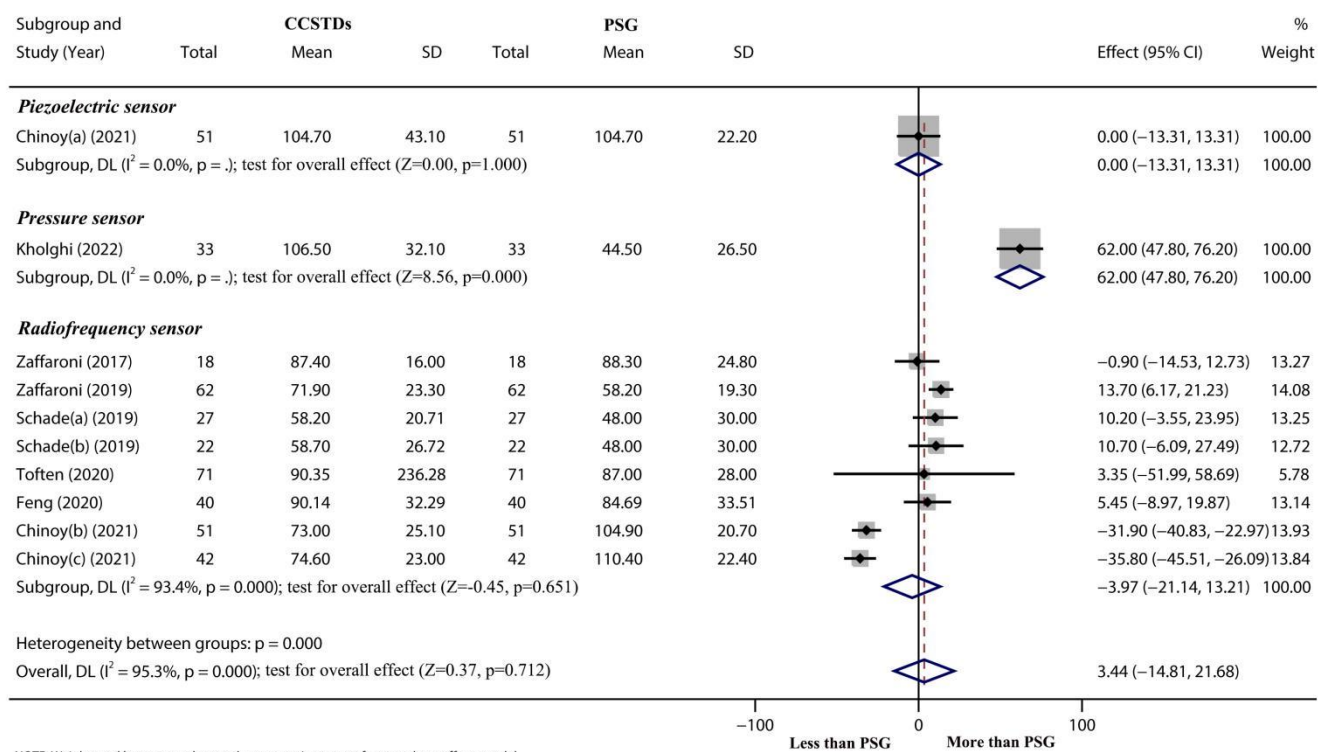


Figure S28. Forest plot meta-analyses for sensors subgroup - REM(min).

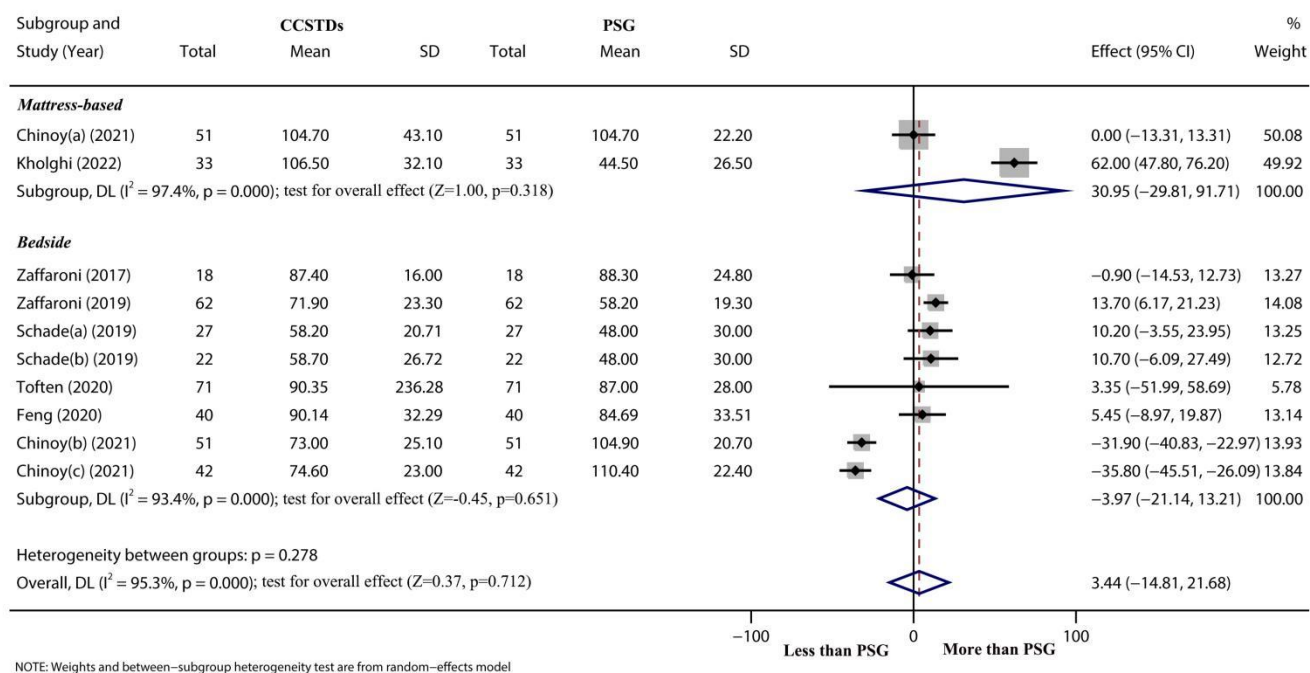


Figure S29. Forest plot meta-analyses for devices type subgroup - REM (min)

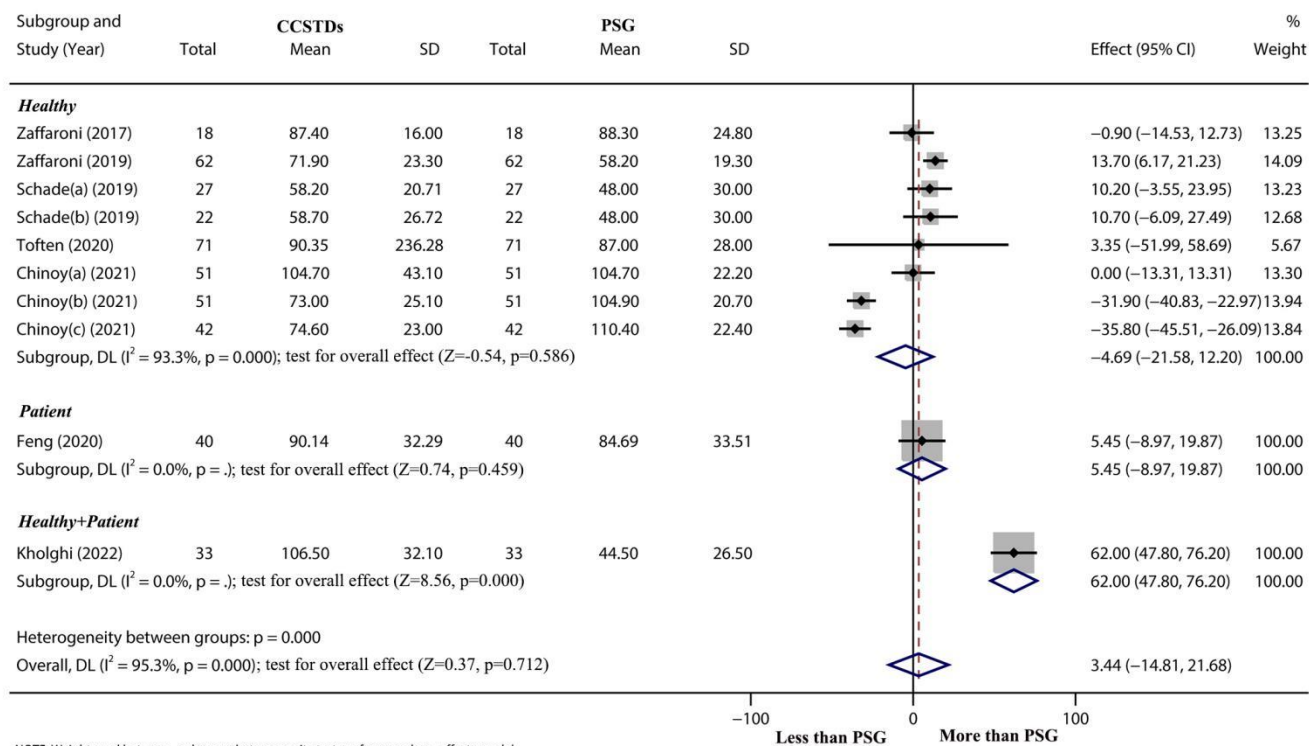


Figure S30. Forest plot meta-analyses for participant types subgroup - REM(min).

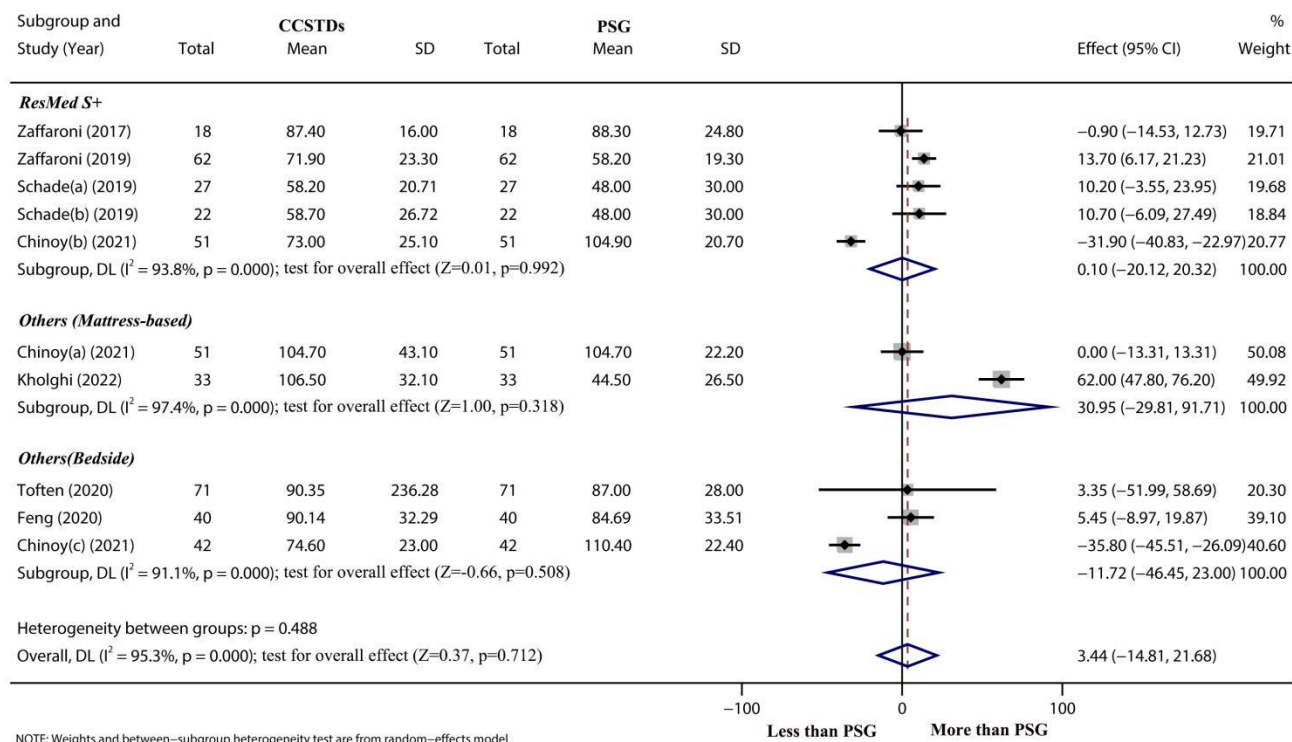


Figure S31. Forest plot meta-analyses for brands subgroup - REM(min).

- REM

The subgroups analyses in Figures S28 to S31 revealed no significant difference compared with PSG except a significant overestimation in pressure sensor (n=1 study; pooled mean =62.00min, 95% CI 47.80 to 76.20; P<.001), and Healthy+Patient (n=1 study; pooled mean =62.00min, 95% CI 47.80 to 76.20; P<.001). Since only one study evaluated piezoelectric sensor, pressure sensor, Patient, and Healthy+Patient, testing for heterogeneity was not relevant, but significant heterogeneity was detected in others.

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