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Percentile Ranks for Walking Speed in Subjects 70-79 Years: A Meta-Analysis

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ABSTRACT
It has been suggested that walking speed is the sixth vital sign. To adequately assess the status of walking speed of patients, normative data or percentile ranks are required. The purpose of this study was to develop percentile ranks for walking speed using a meta-analytic approach for independent, community-dwelling males and females between 70 and 79 years of age. Using PubMed and CINAHL, articles were included in the analysis if: 1) subjects were between 70 and 79 years of age; 2) "walking speed" was described as "comfortable," "preferred," "usual," "normal," or "self-selected"; 3) subjects were classified as independent and community-dwelling; 4) data were provided separately for males and female; 5) means, standard deviations (SD) and sample size were presented or easily discerned; and 6) the English language was used. Two systematic reviews (Bohannon and Andrews, Rydwik et al) were also used to help identify relevant studies. Articles were not included if the sampling methods or testing protocol were not well described by the authors. Principal author, country of study, and timing method, mean walking speed, SD, and number of subjects were obtained for each article. Weighted means, pooled SD, and percentile ranks from 5 to 95 were calculated. Samples of 6359 males from 22 studies representing 10 countries and 12064 females from 34 studies representing 12 countries were used for analysis. Minimal Detectable Changes (MDC) were also calculated for 95% and 90% confidence levels. The weighted mean walking speed was 116.72 cm/sec (pooled SD $\pm$ 18.77) for males and 105.49 cm/sec (pooled SD $\pm$ 21.20) for females. Percentile ranks from 5 to 95 were calculated for males and females. For females, the MDC_{95} was 10.18 cm/sec, while the MDC_{90} was 8.57 cm/sec. For males, the MDC_{95} was 9.01 cm/sec, while the MDC_{90} was 7.59 cm/sec. Percentile ranks are easy to explain and easy to understand, and may be used as adjunctive information during routine healthcare visits.

INTRODUCTION

Adequate mobility is essential for individuals to maintain an independent and active lifestyle. Because of its prevalence, decreased mobility is particularly problematic among older adults. Walking is a common means of mobility for most individuals, whether in the home or the community. The World Health Organization defined walking in its International Classification of Function as "moving along a surface on foot, step by step, so that one foot is always on the ground, such as when strolling, sauntering, walking forwards, backwards, or sideways."[1] The speed at which an individual walks can be a predictive of overall function and the assistance level required in performing everyday tasks.[2-4] However, data on normative walking speed values by age group are sparse.

Walking is a complex functional task that requires full body support, correct timing, power, balance and coordination.[4] Walking places high demands on the brain, spinal cord, muscles, joints, lungs and heart, and requires coordination among the musculoskeletal, neuromuscular, and cardiovascular systems.[4] An individual's walking speed also depends on cognition, mental health, and motivational level.[4]

Walking speed has been shown to correlate with functional ability, balance, and coordination in older adults.[4] It is associated with future hospitalizations, increased risk of dependency, fall risk, increased risk of institutionalization, decreased mobility, and mortality.[5-47] It has recently been proposed as the sixth vital sign, along with blood pressure, heart rate, respiratory rate, pain, and temperature.[4]

Researchers have found high intra- and inter-rater reliability when measuring comfortable walking speed.[3,4,48] A systematic review by Rydwik et al examined the validity and reliability of walking speed distances ranging from 2 meters to 40 meters in institutionalized and community-dwelling adults ages 60 years or greater.[3] Their findings suggest that comfortable walking speed is a highly reliable measure in both community-dwelling and mixed settings, such as nursing homes.[3]

A decrease in walking speed may provide clinicians an early warning sign of possible disruptions in one or many body systems. Early detection of decline in function can lead to early intervention for older adults, which may result in fewer hospitalizations and increased functional independence. For walking speed to have clinical relevance and applicability in the clinic, normative, reference values by age group and sex are required.

Peters et al reported the reliability and validity of walking speed measurements for the 4-meter walk test (4MWT) and the 10-meter walk test (10MWT) in healthy, older adults.[48] Both tests were found to have high test-retest reliability, with intraclass correlation coefficients (ICC) ranging from .96 to .98. These authors also examined the reliability of two timing methods: stopwatch and automatic timer. Both methods had similar standard errors of measurement, between 0.04 and 0.08 cm/s. The agreement between the two methods was also high with ICC values ranging from 0.99 to 1.00. They concluded that measurement of both the 4MWT and 10MWT were reliable and valid using either a stopwatch or automatic timer, and both testing distances rendered walking speed values with excellent agreement. However, Peters et al also noted that for clinical use, testing distances should not be used interchangeably for the same patients over time.[48]

References values, in the form of percentile ranks, may be calculated using the area under the Gaussian (normal) distribution. They are easy to calculate, easy to explain, and easy to understand. Minimal detectable change (MDC) is the smallest change in a score that is result of an actual change in performance and not the result of measurement error or chance.[49] It is the smallest difference in scores for repeated measures that is considered real. [50] MDC is the product of the standard error of the measurement for a test, the critical value chosen by the investigator (usually at a significance level of .05 or .10), and the square root of two.

Researchers have focused on walking speed in populations presenting with significant gait deviations as a result of disease or trauma such as Parkinson's disease, cerebral vascular accidents, Alzheimer's disease, and post-hip surgery. Little of the literature, however, is applicable to healthy, community-dwelling older adults. The purpose of this meta-analysis was to identify data on comfortable walking speed in individuals aged 70 to 79 years. Using these data, weighted means and pooled standard deviations could be calculated to develop reference values and minimal detectable change scores that can be used in a clinical setting. These values can be used to inform patients about their functional level in reference to the performance of a population and may help to identify those patients who will benefit from early intervention.

METHODS

A search was conducted in the PubMed and the Cumulative Index of Allied Health Literature (CINAHL) databases using the search terms "walking speed OR gait speed." Inclusion and exclusion criteria for articles can be found in Table 1. Abstracts and titles were reviewed to determine relevance. Full-text, portable document format (PDF) articles were obtained for further review if gait speed measurements were collected in subjects between 70 and 79 years of age. Reference lists of appropriate studies were also examined to locate additional studies.

During the course of data collection, two systematic reviews were identified in which the authors investigated walking speed in older adults.[3,5] These articles were used to locate additional studies. If primary study authors did not report data separately for males and females, means and standard deviations (SD) reported in the meta-analysis by Bohannon et al were used.[5] Similarly, if authors did not report data separately for the age group used for inclusion, means and SD reported by Bohannon et al were used.[5] Means, SD, and number of subjects were obtained from or calculated for each dataset and entered into two Microsoft Excel spreadsheets – one for males and one for females. The main author, country of study, and timing method were also included in the spreadsheet.

Procedure for Calculating the Weighted Mean

From each article, the arithmetic mean was obtained. The weighted mean was calculated as the overall sum of individual scores divided by the number of scores from all subjects. The formula for calculating the weighted mean can be found in Equation 1.[51]

$$\overline{X} = \frac{\sum x}{n} \Rightarrow \sum x = (\overline{X})(n) \tag{1}$$

Procedure for Calculating the Weighted Standard Deviation using the Inverse Variance Method

Standard deviations were obtained for each group. The variance was calculated as the square of the standard deviation. The inverse of the variance (one over the variance) was then calculated. The average of all the inverse variance (average inverse variance) was calculated. The inverse of the "average inverse variance" was then calculated. The square root of the inverse of the "average inverse variance" was calculated and defined as the weighted standard deviation. The formula for calculating the weighted standard deviation can be found in Equation 2.[52]

$$weighted\ SD = \left(\frac{1}{\frac{\sum \frac{1}{\sigma^2}}{n}} \right)^{.5} \tag{2}$$

Procedure for Determining the Percentile Rank Value

The formula for calculating z values from means and standard deviations (Equation 3) was used to determine percentile ranks. Equation 4 is a transformation of Equation 3. Percentile values from 5 to 95 were calculated using the area under the normal curve associated with percentiles .05 to .45 below and above the mean at intervals of .05.

$$z = \frac{X - \overline{X}}{sd} \tag{3}$$

$$X = [(z)(sd)] + \overline{X} \tag{4}$$

Procedure for Calculating Minimal Detectable Change

Minimal Detectable Change (MDC) was calculated using a z value of 1.96 for a 95% confidence level and a z value of 1.65 for a 90% confidence level, with Equation 5. Intra-rater correlation coefficients reported by Peters et al. were used for calculating the MDC. [48]

$$MDC = Z \cdot \sqrt{2} \cdot (SD) \cdot (\sqrt{1 - ICC} \tag{5}$$

Table 1. Inclusion and Exclusion Criteria for Articles

Inclusion Criteria	
	• Walking speed described as "comfortable," "preferred," "usual," "normal" or "self-selected" pace
	• Subjects were between 70 and 79 years of age
	• Subjects were classified as community-dwelling, healthy individuals
	• English-language
	• Means, standard deviation, and counts (n) were either presented or were easily discerned from the values reported.
	• Data for males and females were reported separately
Exclusion Criteria	
	• Sampling methods or testing protocol were not well described by the authors.
	• Data for 70 to 79 year old subjects were not reported separately.

RESULTS

The countries of origin of studies for females between 70 and 79 years and number of subjects can be found in Table 2. The overall mean for comfortable walking speed in females was 105.49 cm/sec with SD $\pm$ 21.20 cm/sec, based on a sample of 12393 subjects. The most common device used for measuring walking speed was a stopwatch (68%), followed by a gait mat (18%), and a timing unit (15%). Studies from the United States were most common (48%), followed by Australia (12%), Japan (9%), and Sweden (9%). Subjects from the United States represented 70% of the total sample used for analysis, followed by Spain with 10%. There was no predominant protocol for the distance of the walking course; some authors used the six-meter walk test while others used the 30-meter walk test or the 10-meter walk test. Authors who used the gait mat were limited in distance walked by the length of the mat. Appendix A lists the studies for females used for analysis, along with the principle author, country of origin, measuring device used for collecting data, mean, SD, and the count (n). The I^2 statistic indicated that the mean walking speeds across articles were, indeed, heterogeneous.

The countries of origin of studies for males between 70 and 79 years and number of subjects can be found in Table 3. The overall mean for comfortable walking speed in males was 116.72 cm/sec with a SD of $\pm$ 18.77 cm/sec, based on a sample of 6359 subjects. For the studies in the analysis, the most common device used for measuring walking speed was a stopwatch (73%), followed by a gait mat (15%), and a timing unit (12%). Again, studies from the United States were the most frequent (45%), followed by Sweden (14%). Subjects from the United States represented 67% of the total sample used for analysis, followed by China - Hong Kong with 11%. Again, there was no predominant protocol for the distance of the walking course.

Percentile ranks calculated from the area under the curve for the Gaussian distribution can be found in Table 4. Minimal Detectable Changes (MDC) was calculated using a z value of 1.96 for a 95% confidence level and a z value of 1.65 for a 90% confidence level. The test-retest reliability coefficient of .97 was used based on the values reported by Peters et al.[48] For females, the MDC_{95} was 10.18 cm/sec, while the MDC_{90} was 8.57 cm/sec. For males, the MDC_{95} was 9.01 cm/sec, while the MDC_{90} was 7.59 cm/sec.

Table 2. Country of Origin of Studies for Females Between 70 And 79 Years and Number of Subjects

Country	Studies	Subjects
Australia	4	402
Canada	1	14
Germany	1	106
Holland	1	41
China - Hong Kong	1	665
Israel	1	11
Italy	1	253
Japan	3	446
Spain	1	1226
Sweden	3	223
Thailand	1	329
United States	16	8677
TOTAL	33	12393

Table 3. Country of Origin of Studies for Males Between 70 and 79 Years and Number of Subjects

Country	Studies	Subjects
Australia	2	177
Germany	1	141
Holland	1	17
China - Hong Kong	1	708
Italy	1	213
Japan	1	219
Spain	1	370
Sweden	3	190
Thailand	1	180
United States	10	4144
Total	22	6359

Table 4. Percentile Ranks for Walking Speed for Community-Dwelling Males (N=6359) and Females (N=12393) Age 70-79 Years

	Males				Females		
Percentile Rank	cm/sec	m/sec	MPH		cm/sec	m/sec	MPH
90	140.77	1.41	3.15		132.66	1.33	2.97
85	136.17	1.36	3.05		127.46	1.27	2.85
80	132.52	1.33	2.96		123.33	1.23	2.76
75	129.38	1.29	2.89		119.79	1.20	2.68
70	126.56	1.27	2.83		116.61	1.17	2.61
65	123.95	1.24	2.77		113.66	1.14	2.54
60	121.48	1.21	2.72		110.86	1.11	2.48
55	119.08	1.19	2.66		108.15	1.08	2.42
50	116.72	1.17	2.61		105.49	1.05	2.36
45	114.36	1.14	2.56		102.83	1.03	2.30
40	111.96	1.12	2.50		100.12	1.00	2.24
35	109.49	1.09	2.45		97.32	0.97	2.18
30	106.88	1.07	2.39		94.37	0.94	2.11
25	104.06	1.04	2.33		91.19	0.91	2.04
20	100.92	1.01	2.26		87.65	0.88	1.96
15	97.27	0.97	2.18		83.52	0.84	1.87
10	92.67	0.93	2.07		78.32	0.78	1.75
5	85.84	0.86	1.92		70.61	0.71	1.58

DISCUSSION

It was the objective of this meta-analysis to establish normative reference values and minimal detectable change for comfortable walking speed in community-dwelling, older adults between 70 and 79 years of age. Data used in this meta-analysis were collected from 33 studies and 11 countries. The use of a culturally and racially diverse pool of studies makes the findings applicable to a very broad population. Researchers have used different terms to describe comfortable walking speed, including habitual, self-selective, normal, preferred and usual.[4-47] Walking speed is easily measured, time efficient, cost effective, and requires minimal equipment, making it a useful and feasible clinical outcome measure for the evaluation, examination, and development of interventions for patients and clients in the physical therapy setting. It has even been referred to as the sixth vital sign.[4]

The results of our calculations show that the weighted mean for normal walking speed in females is 105.67 cm/sec with a pooled standard deviation of 21.45 cm/sec, and the weighted mean for normal walking speed in males is 116.94 cm/sec with a pooled standard deviation of 18.73 cm/sec. Bohannon et al suggested a normal walking speed of 113.20 cm/sec for females and 126.20 cm/sec for males.[5] However, he did not provide estimates of variation, which are required to calculate reference values. Brach et al indicated that normal walking speed for males and females combined was approximately 1.07 m/sec (107 cm/sec).[13]

Pedrero-Chamizo et al reported reference values for comfortable walking speed among only non-institutionalized, older adults in Spain. Their sample size was considerably smaller than that used in the present analysis (329 males and 1183 females between the ages of 70 and 79 years).[31] The current analysis includes12064 females and 6179 males. The comfortable walking speed reported by Pedrero-Chamizo et al was 163.82 cm/sec for females and 189.07 cm/sec for males. They used only a 30-meter walking course to measure walking speed and calculated their percentile ranks in units of time (sec).[31] These authors provided few details of their methodology for measuring walking speed, and it is not obvious why their results differ so much from average walking speed across studies in the aggregate.

Among the studies incorporated in the current analysis, distances used to measure walking speed ranged between 3.66m (12 feet) and 30m (98 feet). Graham et al examined the prevalence of walking speed protocols used in a variety of subject populations.[46] They noted that authors most commonly instructed subjects to walk at a usual or normal speed. Some authors included acceleration and deceleration phases in their walking course (dynamic starts) while others did not include any phases (static or standing starts). They also noted that distances of 10 meters, 6 meters, and 4 meters were commonly cited; however, 10-meter courses were most commonly used.[46]

We reported the MDC_{95} and MDC_{90} for females at 10.18 cm/sec and 8.57 cm/sec, respectively; for males, MDC_{95} and MDC_{90} were 9.01 cm/sec and 7.59 cm/sec, respectively. Peters et al reported MDC_{95} and MDC_{90} between 0.01 to 0.02 m/sec (1.00 to 2.00 cm/sec)[48]; whereas, Puthoff and Saskowski reported a MDC_{95} of 0.16 m/sec (1.6 cm/sec).[53] Neither Peters et al or Puthoff and Saskowski categorized MDC according to sex.[48,53] We reported separate MDC for each sex. We also believe much of the discrepancies in MDC may be due to precision of measurement, as cm/sec is more precise than m/sec.

No specific testing protocol was predominantly used in the studies included in this meta-analysis (see Appendix A). There are numerous devices for measuring walking speed, including stopwatches, gait mats, photography, radar, and timing devices. A stopwatch was used in approximately 68% of the studies included in our analysis. Although many researchers used a stopwatch to time the distance walked, there was no universal method for measuring time. Therefore, exclusion criteria were used to eliminate articles that did not have well-defined testing protocols.

There may be need for a discussion to establish standardized protocols for measuring walking speed to provide more consistent and homogenous data. As is obvious in Appendices A and B, mean walking speeds varied considerably across studies. A single standardized protocol will not suffice for use in clinical settings because the needs of the patient and the resources available to the clinician may change depending on the clinical setting. All methods that have been incorporated in the current analysis appear to be valid in the measurement of walking speed.

Harvill presented a method for calculating score bands as an indication of the normal variability of a measure.[54] Calculating score bands for normal walking speed is important in the prevention and wellness setting because it helps to estimate the true variability of a normal individual's ability. To determine score bands, means, standard deviations, and reliability coefficients must first be determined. The results of this study could be used to assist in the development of score bands for patients or clients as indicators of their medical status.

A limitation of this meta-analysis is the fact there were no consistent methods used to account for the morbidities that are found in older adults. Authors reported that the subjects in their studies were independent and community dwelling and did not address the different morbidities present unless they were studying a specific population defined by the morbidity. In those cases, subjects were selected if they met the specific inclusion criteria imposed by the author. We were interested in subjects who were described by the authors as independent and community dwelling, regardless of their morbidities.

CONCLUSION

Walking speed has been proposed as the sixth vital sign to be collected during routine healthcare visits. As is the case with the other vital signs (blood pressure, heart rate, respiratory rate, pain, and temperature), normal reference values for walking speed are necessary to interpret a patient's score. If the score is aberrant on the negative side, the clinician must note, and if potentially probative, explore the underlying reasons for this deviation from normality. A positive aberration, of course, may also be noteworthy. In either case, a deviation from normality requires defining what is “normal.”

The weighted mean for walking speed in females between 70 and 79 years of age was 105.67 cm/sec with a pooled standard deviation of 21.45 cm/sec and the weighted mean for walking speed in males was 116.94 cm/sec with a pooled standard deviation of 18.73 cm/sec. The MDC_{95} and MDC_{90} for females were 10.18 cm/sec and 8.57 cm/sec, respectively. The MDC_{95} and MDC_{90} for males were 9.01 cm/sec and 7.59 cm/sec, respectively. From these results, it was possible to develop normal reference values that can be used in a clinical setting for examination, evaluation, and development of a plan of care. Normal reference values were translated into percentile ranks, which are easy to explain and easy to understand. In terms of future directions for this area of study, the calculation of score bands is also necessary to determine the natural variability of scores in walking speed in patients and clients.

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APPENDIX A
List of Studies for Females Used for Analysis with Principle Author, Country, Measuring Device, Mean, SD, and n

Author	Country	Device	Mean (cm/sec)	SD	n
Lord[22]	Australia	Timer	107.00	17.00	22
Lord[22]	Australia	Timer	101.00	19.00	26
Tiedeman[26]	Australia	Stopwatch	110.80	19.90	225
Hill[38]	Australia	Stopwatch	116.30	66.80	60
Hill[38]	Australia	Stopwatch	109.20	77.80	27
Callisaya[43]	Australia (70 - 74)	Gait mat	121.93	19.17	15
Callisaya[43]	Australia (75 - 79)	Gait mat	104.41	16.41	27
Cyarto[16]	Canada	Timer	122.00	18.00	14
Freiberger[18]	Germany	Stopwatch	129.90	25.20	106
Van Iersel[27]	Holland	Gait Mat	150.00	18.70	41
Woo[6]	Hong Kong (70-75)	Stopwatch	92.16	13.84	665
Laufer[20]	Israel	Gait Mat	96.20	27.20	11
Ble[12]	Italy	Timer	94.70	25.60	253
Aoyagi[9]	Japan (70-74)	Stopwatch	99.00	30.36	50
Aoyagi[9]	Japan (75-79)	Stopwatch	89.00	30.30	19
Kamide[30]	Japan	Stopwatch	135.00	22.00	56
Nagasaki[23]	Japan	Stopwatch	97.00	23.20	108
Nagasaki[23]	Japan	Stopwatch	103.80	27.00	213
Pedrero-Chamizo[31]	Spain (70-74)	Stopwatch	166.67	21.29	724
Pedrero-Chamizo[31]	Spain (75-79)	Stopwatch	158.73	31.59	502
Oberg[45]	Sweden	Timer	110.00	12.00	15
Aniansson[13]	Sweden	Stopwatch	110.00	20.00	194
Willen[28]	Sweden	Stopwatch	116.00	23.00	14
Thaweewannakij[32]	Thailand	Stopwatch	99.00	15.00	329
DePaasquale[17]	USA	Stopwatch	117.50	18.00	10
Lusardi[33]	USA	Gait Mat	125.00	18.00	10
Purser[36]	USA	Stopwatch	108.90	18.30	48
Brach[13]	USA	Gait Mat	104.00	19.00	183
Wolfson[29]	USA	Timer	113.20	19.10	26
Bohannon 1996[5]	USA	Stopwatch	134.30	19.60	21
Leiper[41]	USA	Gait Mat	97.00	21.00	35
Atkinson[11]	USA	Stopwatch	111.00	21.00	1229
Taaffe[25]	USA - female White	Stopwatch	115.38	21.04	847
Taaffe[25]	USA - female Black	Stopwatch	101.69	22.77	723
Bohannon 1997[42]	USA	Stopwatch	127.20	21.10	20
Steffen[39]	USA	Stopwatch	133.00	22.00	22
Bohannon 2008[2]	USA	Stopwatch	93.00	22.90	210
Fitzpatrick[47]	USA	Stopwatch	94.30	23.00	939
Arnadottir[11]	USA	Stopwatch	126.00	28.00	14
Lindsey[21]	USA	Stopwatch	136.00	28.00	34
Aoyagi[9]	USA - Jap-Am (70-74)	Stopwatch	112.00	33.66	273
Aoyagi[9]	USA - Am Cau (70-74)	Stopwatch	90.00	38.69	2557
Aoyagi[9]	USA - Am Cau (75-79)	Stopwatch	83.00	36.18	1258
Aoyagi[9]	USA - Jap-Am (75-79)	Stopwatch	101.00	27.59	218

APPENDIX B
List of Studies for Males Used for Analysis with Principle Author, Country, Measuring Device, Mean, SD, and n

Author	Country	Device	Mean (cm/sec)	SD	n
Brach[13]	USA	Gait Mat	112.00	20.00	108
Callisaya[43]	Australia (75 - 79)	Gait mat	108.60	21.97	26
Callisaya[43]	Australia (70 - 74)	Gait mat	113.69	12.45	27
Van Iersel[27]	Holland	Gait Mat	140.70	13.10	17
Aniansson[8]	Sweden	Stopwatch	120.00	20.00	160
Atkinson[11]	USA	Stopwatch	120.00	21.00	1120
Bohannon 2008[2]	USA	Stopwatch	95.70	22.90	237
Bohannon 1996[5]	USA	Stopwatch	141.80	21.30	22
Bohannon 1997[42]	USA	Stopwatch	133.00	19.60	22
Woo[6]	Hong Kong (70-75)	Stopwatch	101.35	11.66	708
Fitzpatrick[47]	USA	Stopwatch	98.90	20.10	1083
Freiberger[18]	Germany	Stopwatch	139.60	27.60	141
Nagasaki[23]	Japan	Stopwatch	110.50	26.50	84
Nagasaki[23]	Japan	Stopwatch	118.00	24.30	135
Taaffe[25]	USA - male white	Stopwatch	125.00	20.11	927
Taaffe[25]	USA - male Black	Stopwatch	109.10	26.26	544
Pedrero-Chamizo[31]	Spain (70-74)	Stopwatch	193.55	28.57	214
Pedrero-Chamizo[31]	Spain (75-79)	Stopwatch	182.93	25.57	156
Purser[36]	USA	Stopwatch	119.80	14.70	28
Steffen[39]	USA	Stopwatch	138.00	23.00	14
Tiedeman[26]	Australia	Stopwatch	115.60	24.90	124
Willen[28]	Sweden	Stopwatch	132.00	16.00	15
Thaweewannakij[32]	Thailand	Stopwatch	109.00	20.00	180
Ble[12]	Italy	Timer	106.80	23.90	213
Oberg[45]	Sweden	Timer	118.00	15.00	15
Wolfson[29]	USA	Timer	123.20	16.30	39