令和４年度

産業保健調査研究報告書〈調査期間：令和４年４月～令和５年３月〉

林業従事者の傾斜地作業負荷測定方法開発のためのパイロット研究

研究体制

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令和５年３月

独立行政法人労働者健康安全機構

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Table of Contents

1. 背景

林業は重大な労働災害の発生率の高い業種である。労働災害の発生の高い時間帯があり、疲労に関連すると考えられている。疲労は作業負荷と回復（休憩、就業外時間、休日）とのバランスである。森林作業員の作業負荷のうち、主な身体的作業負荷に重い道具の運搬と傾斜地の移動がある。森林作業員の勤務状況や作業環境は国・地域によって違う。広大な森林のある地域では現地に寝泊まりし交代勤務で行うが山口県のような森林では現場に毎日通って作業をしているといわれている。また、傾斜の程度や機械化の程度も異なる。林業従事者の作業負荷を測定した報告は国際的に乏しい。身体的作業負荷は農業のような体幹・四肢の屈伸運動よりも、重量物を運搬しながらの傾斜地移動による身体活動（エネルギー消費）での負担が高いと仮定する。この作業負荷を簡易に測定することができ、客観的に評価することができれば、休憩・休日の取得などの作業方法や自動化機械導入の成果の評価が可能となる。屋外での身体活動の評価は、心拍数計、加速度計が用いられているが、様々な要因の影響を受けることや傾斜地と平地の区別が難しい欠点がある。実際の森林作業員の作業負荷を把握するために、本調査研究では、ウエアラブル測定機器を装着して、傾斜地を上り下りし、身体活動量を簡易測定することが可能であるか確認することをこのパイロット研究の第一の目的とした。身体活動量から作業の身体活動強度がわかる。また、作業負荷の実態を評価するために、林業従事者の業務を把握する必要があるが、これまで日本林業従事者の医学領域での報告がほとんどなく、森林作業員の作業種類の分布を明らかにすることをパイロット研究の第二の目的とした。

本調査研究の計画は、独立行政法人労働者健康安全機構本部医学系研究倫理審査委員会で承認を受けた。調査研究費用は独立行政法人労働者健康安全機構の交付金であった。研究者は当センターの産業保健相談員等で、それ以外の報告すべき利益相反はなかった。

2. 調査 1

2.1. 目的

日本の森林は傾斜地にあること、湿潤な気候のため下草が育ちやすいことが特徴で、森林作業員の作業負荷が高くなる。森林作業として、荷物を負った歩行のエネルギー消費量を推定できるウエアラブル測定機器に測定方法を明らかにすることが目的である。

2.2. 方法

参加者に 6 人の 37-63 歳の男性をリクルートした。測定は森林総合研究所敷地内の森林を模した築山で行った。対象者の食後 2 時間で、森林作業をする服装・装具、20kg の背負子、さらに測定器具を装着してもらい、平地、15 度、30 度の傾斜地を歩行してもらった。平地は 270m、築山は 8m の高さで、15 度と 30 度の傾斜値をそれぞれ 3 往復してもらった。それぞれ歩行の間には、心拍数が落ち着くように休憩を 5 分間程度とった。歩行は 50m/分程度を目標に自由歩行してもらった。

エネルギー消費量は、携帯型呼吸代謝測定装置 K5(コスメッド, イタリア)で、基準となる酸素消費量を測定した。心拍数は Verity Sense(ポラール、フィンランド)を非利き手の前腕に装着してもらい計測した。身体動作加速度から身体活動量を推定できる。動作測定に加速度計 wGT3X-BT(アクチグラフ、米国)を右腰につけてもらった。垂直移動距離がわかれば仕事量を求めることができる。衛星測位システム GNSS を用いた Trimble TDC150 (ニコン・トリンブル、日本)を背負子に固定して水平移動、垂直移動を記録した。すべての装置は、時刻を同期し、パソコンにデータをダウンロードでして、解析を行った。 身長、体重はそれぞれの参加者の歩行開始前に測定した。

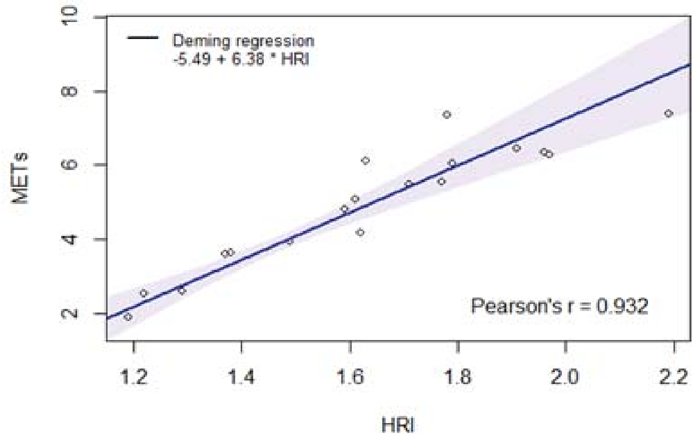
酸素消費量から、活動強度として metabolic equivalent of task (MET)を計算した。心拍数は、安静時の心拍数との比である heart rate index を用いた。また heart rate index(HRI)から エネルギー代謝率 MET を Wicks らの提案した式$ METs=HRI -5 $で推定した。加速度計のデータは、3 軸の加速度(カウント)を合成した vector magnitude(VM)を用いた。GNSS データからは垂直方向の移動距離を用いた。心拍数から得られたエネルギー代謝率との相関を調べた。解析に R(R core team, オーストリア)を用いた。

2.3. 結果

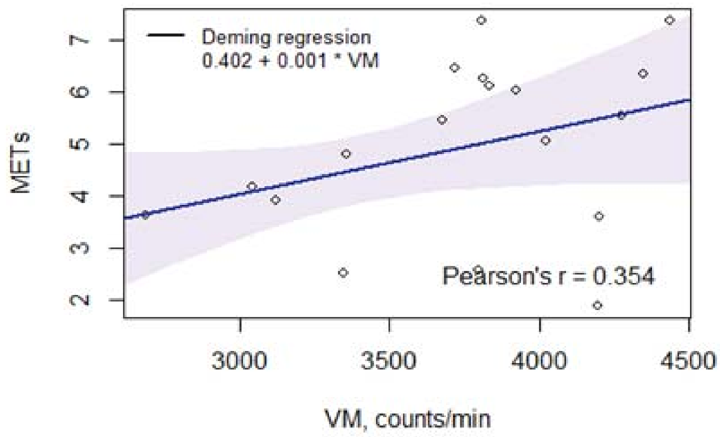
GNSS データの垂直移動測定は基線がずれて移動距離を正確に測ることができなかった。GNSSS データを除いて、検討した。歩行時間に限った解析では心拍数から求める HRI と加速度計から VM を酸素消費量から求めた METs との Pearson 相関は、それぞれ 0.932、0.354 であった。心拍数や酸素消費量は安静時の状態に回復するまでのタイムラグを考慮にいれた場合の相関は、それぞれ 0.843、0.506 であった。いずれも心拍数から求めた HRI の方が相関が高か

った。HRI から推定した MET と酸素消費量から計算した MET とを比較すると、差は 0.134 METs で、その 95%信頼区間は-0.543 METs と 0.811 METs で1MET 以内であった。

(a)


Deming regression
-5.49 + 6.38 * HRI
Pearson's r = 0.932
METs
HRI
2
4
6
8
10
1.2
1.4
1.6
1.8
2.0
2.2

(b)


Deming regression
0.402 + 0.001 * VM
Pearson's r = 0.354
METs
VM, counts/min
2
3
4
5
6
7
3000
3500
4000
4500

(c)

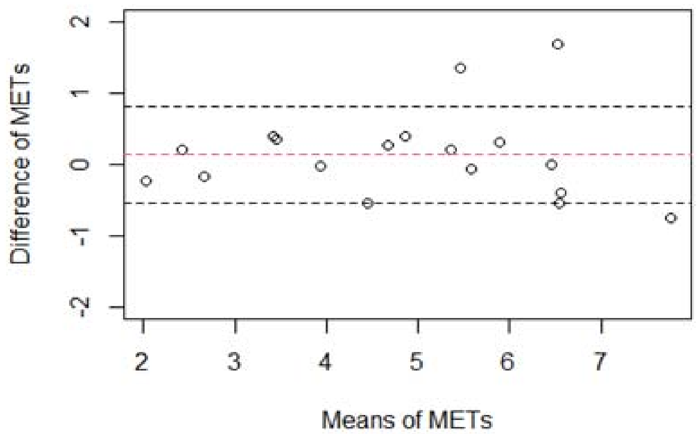

Difference of METs
Means of METs
-2
-1
0
1
2
2
3
4
5
6
7

Figure 1. (a) 心拍数から計算したHRIと酸素消費量から計算したMETの関係、(b)加速度計から計算したVMと酸素消費量から計算したMETの関係、(c)心拍数HRIから推定したMETと心拍数から計算したMETのBland-Altmanプロット

2.4. 考察

傾斜値の移動を測定するには、HRIの妥当性が最も高かった。森林作業には移動だけではなく、チェーンソーを使った伐採(主伐、間伐)、下刈りなど上半身を使う作業もある。加速度右傾やGNSS装置と違い、心拍数計ならばこれらの活動でもエネルギー代謝率を推定ができると考えられる。また用いた心拍数計は軽量(17g)で作業者にも測定の負担は軽いと考えられる。実際に森林作業で心拍数モニターを行ってみることができると考える。

3. 調査 2　調査票の集計

3.1. 目的

森林作業には、樹木の生育によっていくつかの種類がある。作業の負荷は、森林作業による疲労や事故リスクとも関連すると考えられる。森林作業種類ごとの作業負荷程度を携帯型デバイスを用いて調べることができる。このような調査を行うために、事前に林業作業の種類、作業時間を把握しておき、調査方法を検討する必要がある。作業種類と従事時間に関する情報があまり公開されていない。山口県内に 6 か所の団体、森林作業員は 300 人程度であるという伝聞情報があり、今回山口県全体で森林作業員を対象に森林作業について調べることとした。目標は、従事する作業の偏り、作業の時間、それに関係する要因を明らかにすることであった。

3.2 方法

山口県内に 6 か所の森林組合あるいは民間事業体があり、それぞれの 5-10 人で構成される班で作業を行っていた。それぞれの森林組合あるいは民間事業体の一つの班の作業員に調査に回答いただくように依頼を行い、47 人の対象者が選ばれた。森林組合あるいは民間事業体を通して調査票を配布し、郵送で回答を得た。調査は、2022 年 6-7 月に行った。質問票は別添えの通りである。質問票は 40 人から回収でき、それぞれの質問ごとに選択肢の集計あるいは代表値を求めた。

3.3. 結果

問 1 作業内容

地拵え、植栽、下刈り、除伐、間伐の作業には半分以上の森林作業員が従事し、枝打、主伐、搬出には 30%以上が従事していたが、製材・市場の作業に従事している森林作業員は少なかった。調査時期が 6－7 月の回答では、最近 1 か月の作業として下刈り、間伐、搬出が多かった。

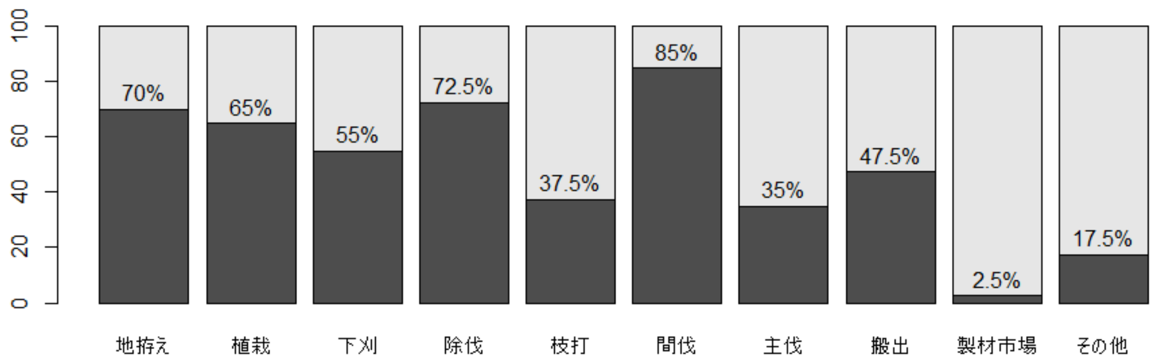


図 1-1. 1 年間の作業種類

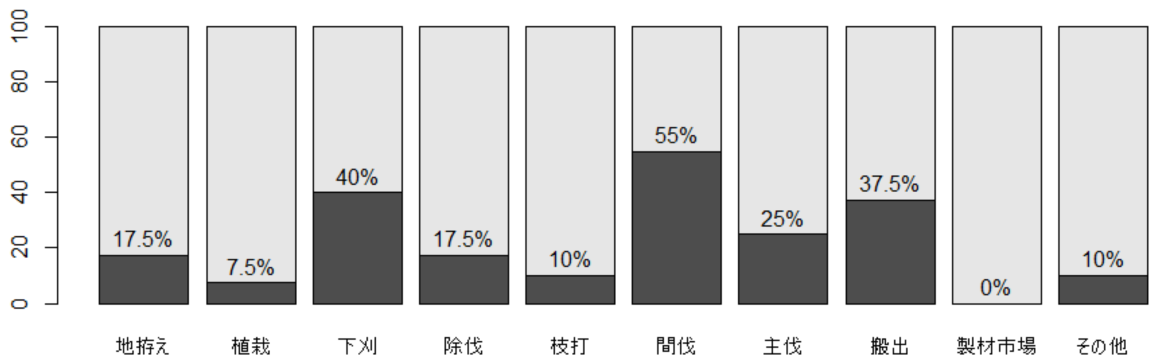


図 1-2. 1 か月間の作業種類

問 2 1 週間あたりの就業日数

週5、6日の就業であった。

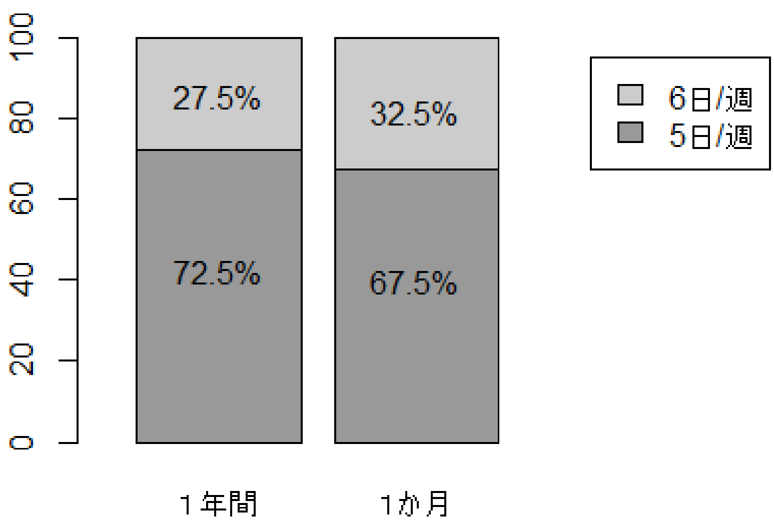


図 2. 1 週間当たりの就業日数

問 3 最近の平均的な林業に従事する時間

多くが 1 日 8 時間勤務で、平均も 8.0 時間であった。

表 3.　林業従事時間

	最小値	第 1 四分位	中央値	平均値	第 3 四分位	最大値
1年間	2	8	8	8.03	8.62	10
1か月	2	8	8	7.96	8.62	10

問 4 休憩回数と時間

長い休憩は、回答のあった 31 人でほとんど 12 時から 1 時間であった。2 名は 12 時前から 1 時間超の休憩で、1 名は 60 分未満の昼休みであった。

短い休憩には 33 名回答し、1 日に 1 回から 4 回の休憩をとっていた。2 名は休憩なしで、1 名 240 回と回答した。10、15 時ぐらいから休憩をとる人が多く、休憩時間は 10～30 分間で、15 分間が多かった。

問 5 通勤

通勤は自宅からで、ほぼ 1 時間以内であった。

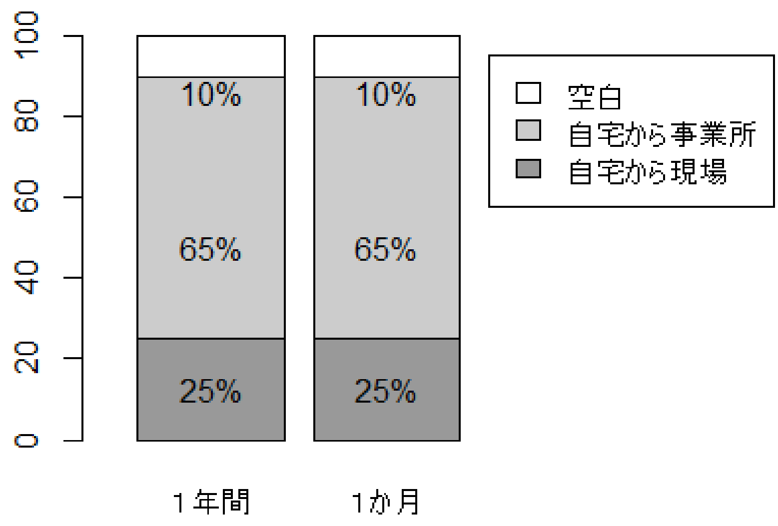


図 5-1. 通勤経路

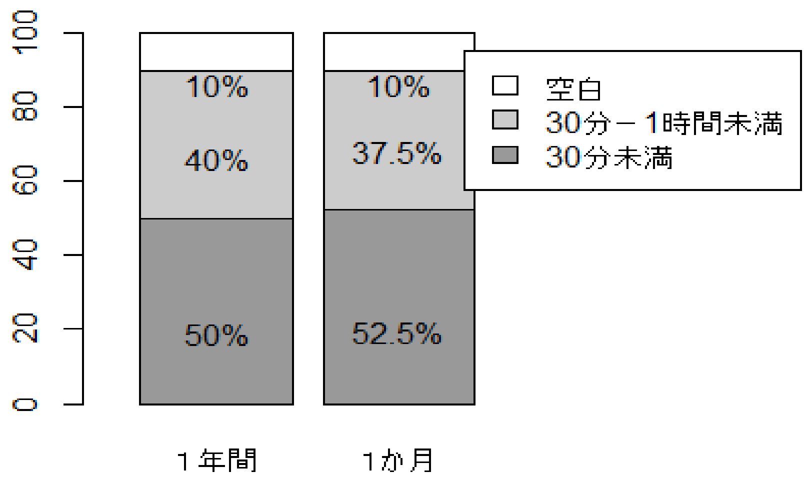


図 5-2. 通勤時間

問 6, 7 交代勤務・夜勤

交代勤務、夜勤があるという回答はなかった。

問 8, 9 収入・副業

収入は日給が 32.5%、月給が 57.5%、個人事業主が 10.0%であった。副業をしている人はいなかった。

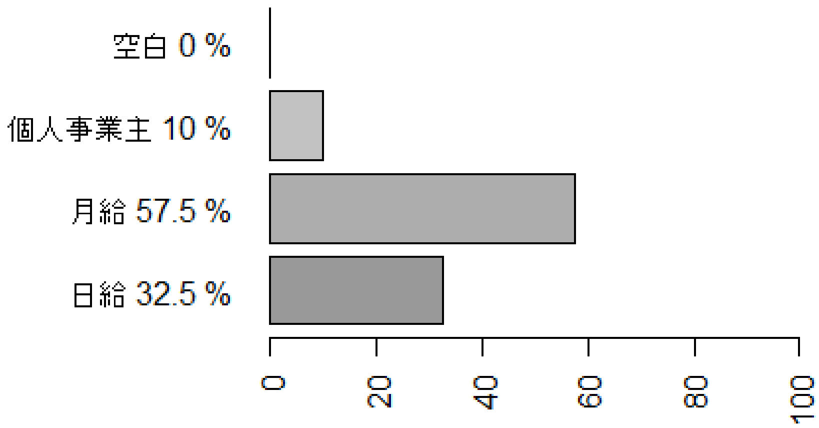


図 8. 収入

問 10 林業経験年数

経験年数の範囲は、0.5 から 45 年で、平均 13.96 年だった。

表 10. 林業経験年数

最小値	第 1 四分位	中央値	平均値	第 3 四分位	最大値
0.5	4.5	14	13.96	21.25	45

問 11 事故

事故の経験者は 47.5%、事故になりそうだった人は 42.5%、事故の経験がない人は 10.0%であった。

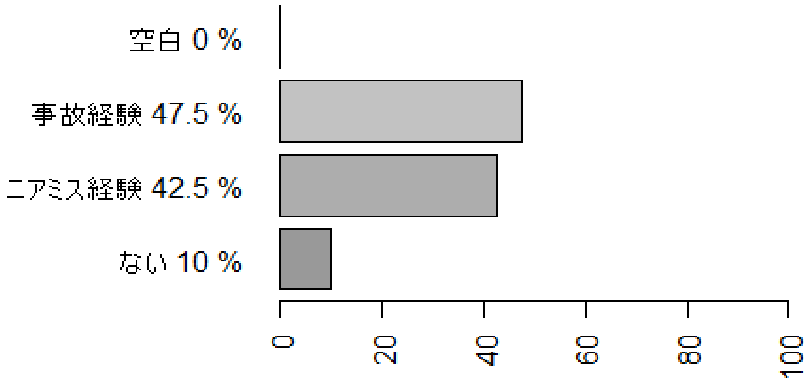


表 11. 事故経験

問 12 現在の健康状態

治療中の人が 10.0%、健診で指摘されているが未治療中の人が 2.5%であった。

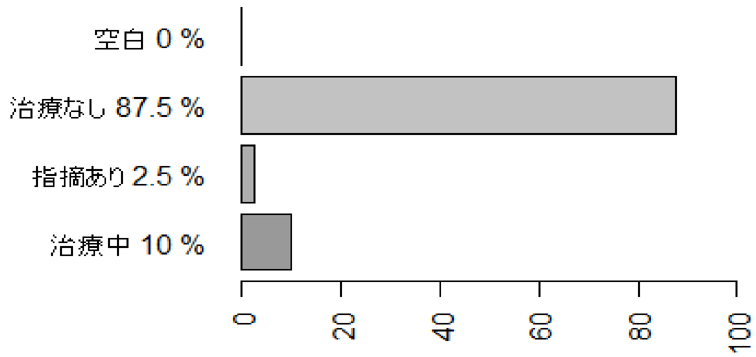


図 12.　健康状態

問 13 最近 1 か月の睡眠

重複回答があった。よく眠れると回答したのは 67.5%であった。昼間眠たくなるのは 15%であった。ただし眠れると重複回答があった。

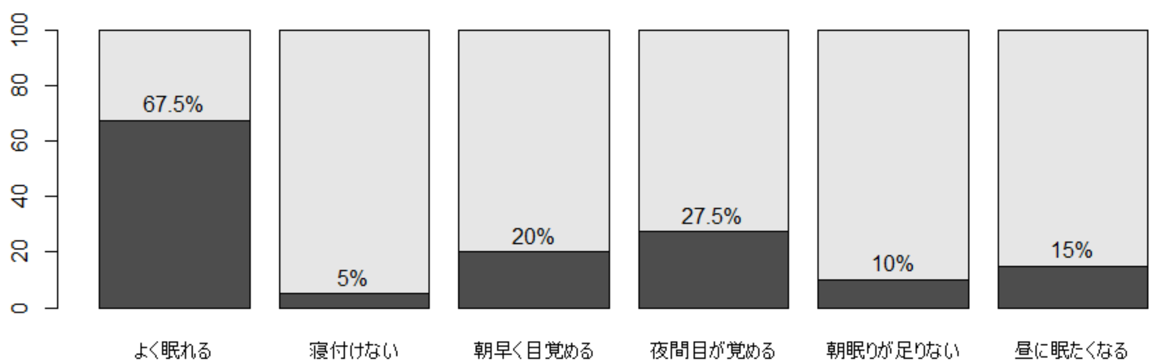


図 13. 睡眠

問 14 住まいの状況

結婚して同居している人は 62.5%、別居している人が 2.5%、結婚していない人が 35.0%であった。

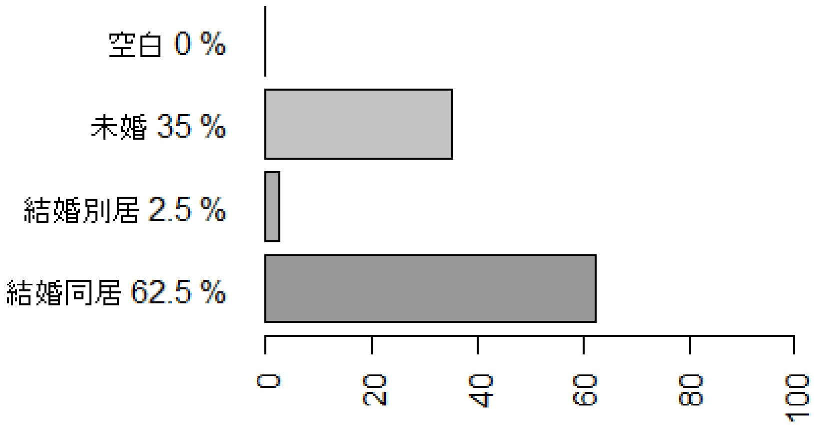


図 14. 世帯

問 15 性別

97.5%が男性、2.5%が女性であった。

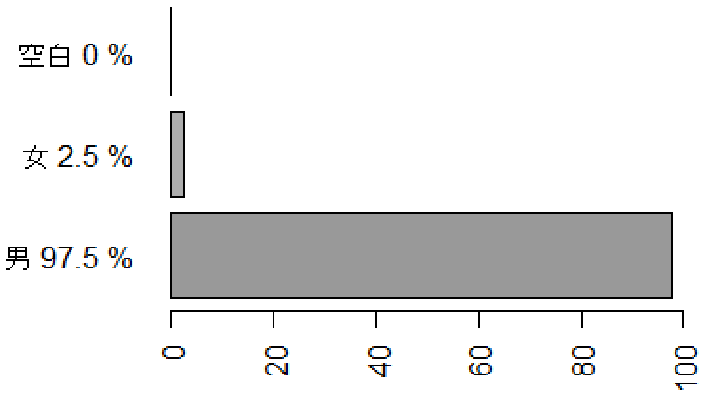


図 15. 性別

問 16 年齢

回答した 36 人の平均年齢は 44.25 歳で、範囲は 21 歳から 68 歳であった。

表 16. 年齢

最小値	第 1 四分位	中央値	平均値	第 3 四分位	最大値	空白人数
21	37.75	45.5	44.25	50.25	68	4

3.4. 考察

作業の種類を知ることができた。1 年間ですべての作業に従事するわけではないが、地拵え、植栽、下刈り、除伐、間伐、枝打、主伐、搬出の作業に多くの森林作業員が従事していた。また季節によって取り組む作業の違いがあることが示唆された。海外のような宿泊所施設（宿泊する飯場）の利用はなく、通勤の負担も大きくなさそうであった。また、現在の健康状態について、治療の有無、睡眠についての質問からはとくに目立った大きな問題はなさそうで、作業内容自体に注目して作業負荷を評価すればよいだろう。

年齢も経験年数もさまざまであるが、多くの森林作業員が事故の経験、あるいは事故になりそうになった経験があった。自由記載にも危険な作業への自覚を促すコメントがあり、事故対策は必要である。今回の結果から 1 年間を通して複数の事業場（森林組合や民間団体）で調査を実施すれば山口県内の森林作業員の作業負荷を知ることができると推察した。

4. まとめと将来展望

複雑な地形で行われる森林作業のエネルギー消費量を心拍数で測定できることが分かった。心拍数を安静時の心拍数との比で表す HRI を用いるとよい。また、森林作業員は 1 年を通して多くの作業に従事し、季節によって作業内容が変わっていることが分かった。とくに夏には下刈りや間伐が多くなっていた。

本調査研究で得られた知見から、森林作業員の作業種類を考慮した作業負荷を明らかにするメイン研究を次のように組み立てることができる。調査の対象は山口県内森林作業員とする。現在山口県内に 6 か所の森林組合あるいは民間事業体がある。それぞれ 5～10 人で構成される班がいくつかあり、班ごとに 1 年間を通して森林の育成（季節）に合わせた森林作業に従事している。作業日を単位として森林作業員の心拍数モニターを行う。測定日の 1 日の測定は、一つの班の全員（平均 7 人、5～10 人）にお願いする。1 日を通して作業が行える天候の日に行う。調査研究全体の測定日は、1 年を通して測定するため令和5年6月から令和6年5月までのそれぞれ 1 か月のうち 2 日とし、1 日の測定日には1か所の団体の測定日に作業を行う1班を割り当てる（平均 7 人、5～10 人）。測定日に作業を行っている班で測定を行うため、一人の森林作業員には調査研究期間に2日以上測定日があたることがある。被検者には、身長、体重、性別、年齢、森林作業の経験年数、測定日の作業種類を尋ねる。研究者は測定日の天候、気温、作業場所の位置、地面の状態を記録する。また研究者は観察した作業の前後から作業内容も記録する。これらをもとに、主な作業内容に分類して作業負荷強度を明らかにする。測定した結果から、森林作業員、作業の管理者、林業関係者に作業負荷強度を知っていただき、作業管理、作業補助機機器の開発に活用してもらう。今回調査研究は将来の調査研究に役立つ知見を得ることができた。

5. 付録　調査票別添

調査票 別添

令 和 4 年　○○月

林業に従事される労働者の方へ
　および　林業関係者の方へ

独立行政法人 労働者健康安全機構
山口産業保健総合支援センター

林業従事者の作業に関する調査のお願い

平素は、当センターの活動にご理解ご支援を賜りましてまことに感謝しております。

当センターでは、事業場の規模に限らず労働者の健康管理に関する支援、助言、教育などを行い労働者の健康の向上を図っております。

このたび、「林業従事者の傾斜地作業負荷測定方法開発のためのパイロット研究」として林業従事者の作業負荷と疲労に関する調査を行っております。これまでの知見が少なく、まず労働実態を把握するための質問票を作成することとし、その質問票の調査可能性を確かめることとしました（パイロット研究といいます）。

林業事業所、森林組合等を通して、林業従事者にご回答をいただきたいと存じます。林業従事者個人を対象に、無記名で調査を行います。

調査対象者数はパイロット研究のため 30 人を予定しております。ご回答いただくと調査にご協力同意いただいたものとします。ご回答は集計し、労働者の健康保持増進に貢献できるように努めてまいります。データをまとめた集計結果は公開し、関係機関での事業活動に活かせるようにしていきます。

記入された質問票は　○○月　○○日まで同封した封筒でご返送ください。

なにとぞ趣旨をご理解の上、ご協力よろしくお願いします。

（ 連絡先 ）
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林業従事者の就業状況と疲労に関連する要因を調査するための質問票を作成するための予備調査です。回答に 10 分ぐらいかかります。最後までご協力よろしくお願いします。

あてはまるところ□にチェック（✔）を、かっこ（　　　　）には数字をご記入ください。

問番号	質問項目		
問 1	最近行った工程に当てはまるものはどれですか（当てはまるものすべて）。		
		1-1 最近 1 年間に行った工程	1-2最近 1 か月間に行った工程
	a　地拵え	□	□
	b　植栽	□	□
	c　下刈	□	□
	d　除伐	□	□
	e　枝打	□	□
	f　間伐	□	□
	g　主伐	□	□
	h　搬出	□	□
	i　製材・市場	□	□
	j　その他	□	□
問 2	最近の 1 週間あたりの何日林業に従事しますか（ひとつ）。		
		2-1 最近 1 年間の平均的な労働日数	2-2 最近 1 か月間の平均的な労働日数
	1.　1 日/週	□	□
	2.　2 日/週	□	□
	3.　3 日/週	□	□
	4.　4 日/週	□	□
	5.　5 日/週	□	□
	6.　6 日/週	□	□
	7.　7 日/週	□	□
問 3	最近の平均的に林業に従事する労働時間（休憩時間を含む）		
		3-1 最近 1 年間の林業従事日の平均的な 1 日労働時間	3-2 最近 1 か月間の林業従事日の平均的な 1 日労働時間
		休憩時間を含めて（　　　　　　）時間/日	休憩時間を含めて（　　　　　　）時間/日

問 4	最近の林業に従事する平均的な日の休憩回数と時間		
		4-1 最近 1 年間の林業従事日の平均的な休憩	4-2 最近 1 か月間の林業従事日の平均的な休憩
60 分以上 	60 分以上の休憩 a 回数	（ ）回/日	（ ）回/日
	1 回目 b 開始時刻 c 時間	1 回目 （ 時 分） （ ）時間/回	1 回目 （ 時 分） （ ）時間/回
	2 回目 d 開始時刻 e 時間	2 回目 （ 時 分） （ ）時間/回	2 回目 （ 時 分） （ ）時間/回
60 分未満 	60 分未満の休憩 a 回数	（ ）回/日	（ ）回/日
	1 回目 b 開始時刻 c 時間	1 回目 （ 時 分） （ ）時間/回	1 回目 （ 時 分） （ ）時間/回
	2 回目 d 開始時刻 e 時間	2 回目 （ 時 分） （ ）時間/回	2 回目 （ 時 分） （ ）時間/回
	3 回目 f 開始時刻 g 時間	3 回目 （ 時 分） （ ）時間/回	3 回目 （ 時 分） （ ）時間/回
	4 回目 h 開始時刻 i 時間	4 回目 （ 時 分） （ ）時間/回	4 回目 （ 時 分） （ ）時間/回

問 5	通勤時間はどのくらいですか。経路と時間でそれぞれ一つ		
		5-1 最近 1 年間の平均的な通勤	5-2 最近 1 か月間の平均的な通勤
	通勤の経路 1. 自宅から現場	☐	☐
	2. 自宅から事業所	☐	☐
	3. 現場近くに宿泊 （宿泊所から現場）	☐	☐
	通勤時間 1. 30 分未満	☐	☐
	2. 30 分 ～ 1 時間未満	☐	☐
	3. 1 時間 ～ 1 時間 30 分未満	☐	☐
	4. 1 時間 30 分 ～ 2 時間未満	☐	☐
	5. 2 時間以上	☐	☐

問 6	交代勤務がある
	1. □　はい　　　2. □　いいえ
問 7	夜勤（午後 10 時から午前 5 時までの間に働く時間）がある
	1. □　はい　　　2. □　いいえ
問 8	給与の支払い方法の基準は次のどれですか。（ひとつ。個人事業主）
	1. □　時給　2. □　日給　3. ☒　週給　4. □　月給　5. □　個人事業主
問 9	林業以外にも仕事をされていますか。
	1. □　はい　　　2. □　いいえ
問 10	林業従事の経験年数
	（　　　　　　　）年
問 11	林業従事中に事故にあったことや、事故になりそうになった経験がありますか。
	1. □　ない　2. □　事故になりそうだった（ニアミス） 3. □　事故にあった
問 12	現在の健康状態
	1. □　治療中　2. □　治療はしていないが健診で指摘されている 3. □　健康
問 13	最近 1 か月間の睡眠の様子はどうですか。（当てはまるものすべて）
	a □　よく眠れる　b □　寝付けない　c □　朝早く目覚める d □　夜間目が覚める　e □　朝眠りが足りない　d □　昼に眠たくなる
問 14	現在 1 か月間のお住まいの状況
	1. □　結婚している（同居）　2. □　結婚しているが別居 3. □　結婚していない
問 15	性別
	1. □　男性　　　2. □　女性　　　3. □　答えたくない
問 16	年齢
	（　　　　　　　）歳　　　　□　答えたくない
問 17	これまでの質問について、コメントがありましたらご記入ください。 答えにくい質問がある、林業従事者には当てはまらない、林業従事者の業務には必要ない項目がある　など　問の番号のご記入とあわせてお答えください。
問 18	回答記入日　（　　　　　）月　（　　　　　）日

最後までお答えいただき、ご協力ありがとうございました。
返信用封筒に入れて投函してください。
差出人のお名前は不要です。

forests

MDPI

Brief Report

Energy Expenditure Estimation for Forestry Workers Moving on Flat and Inclined Ground

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Abstract: Forestry workers endure highly physical workloads. Japanese forestry workers experience additional up-and-down movements due to geographical features. Fatigue is a common cause of injury. This pilot study aimed to determine an appropriate method for estimating energy expenditure while moving across inclined ground to simulate a Japanese forest. Six participants wore a portable indirect calorimeter ($\dot{V}O_2$), heart rate (HR) monitor (17 g), accelerometer (20 g; vector magnitude; VM), and a global navigation satellite system (GNSS) device. They walked shouldering 20 kg of weight on flat, 15°- and 30°-slopes. The time course of HR was similar to that of $\dot{V}O_2$, but that of VM and the vertical movement varied from that of $\dot{V}O_2$. GNSS cannot correctly detect vertical movements. The HR index (HRI), indicating the ratio of activity HR to resting HR, was significantly correlated with the metabolic equivalent of the task (MET) calculated from $\dot{V}O_2$ (r = 0.932, $p < 0.0001$), which fit the previously proposed formula for METs (METs = HRI × 6 − 5). However, VM was not correlated with VM (r = 0.354, $p = 0.150$). We can use HRI to measure the workload of Japanese forestry workers with a small burden in the field.

Keywords: accelerometer; energy expenditure; forestry workers; global navigation satellite positioning system; heart rate index; oxygen consumption; simulated forestry slope

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1. Introduction

Forestry is one of the most hazardous industrial sectors in most countries [1]. According to Japanese statistics, the incidence of absences from work lasting at least four days, including death, was 9.1 times higher in forestry than in all other industries combined in 2021 [2]. The physically and mentally demanding workload in forestry is related to workers' fatigue, which is considered to be a contributing factor to accidents and injuries [3–5]. Japanese forests have different land characteristics from forests in other countries [6]; 37.2% of Japanese forest land has a slope >20°, which is the average among Asian countries, but higher than that in other regions [7]. Steep slopes hamper machinery operation and increase the risk of machine handling [1]. Workers must transfer forestry equipment and tools up and down forest land, in addition to engaging in high-intensity activities. It has been suggested that the physical properties of land establish unique operational systems based on experience and intuition [1,7,8]. Determining the workload of Japanese forestry workers is challenging, particularly when performing a broad range of forestry procedures. A descriptive study to measure the workload in the forestry industry in a temperate climate throughout the year is required to take measures to reduce fatigue and injury.

Heart rate (HR) monitoring is widely used to estimate the workload. Several studies have measured the workload of forestry workers using HR monitors in the field [9–14]. They reported a single task or operation, such as afforestation, pruning, felling, or cable work, and used the crude or HR relative to the maximal or submaximal HR. Relative HR is reliable against inter-individual variability, but is inconvenient for the detection of maximal or even submaximal HR in the field. A few reports on the workload of Japanese forestry workers (walking, mowing, or felling) were also found in the database [15–17], in which HR monitoring was conducted with a small sample size; oxygen consumption as an indicator of energy expenditure was not assessed.

HR and O_2 had a linear relationship, except at low levels of activity (below the flex HR; HR_{flex}) [18,19]. The heart rate index (HRI; actual HR/resting HR) is the most reliable predictor of energy expenditure, not only for healthy people, but also for patients with cardiovascular diseases [20]. The HRI method is applicable in real practice in the forestry field because only the resting HR must be known, whereas the maximal or submaximal HR is not required. To determine the latter, an exercise test using a treadmill or cycle ergometry is needed [21]. Although the HRI method is applicable to forestry work, validation with O_2 consumption has only been tested with workers wearing light clothing under laboratory conditions [20,22,23], and is impractical in the field. Other methods have been proposed to estimate energy expenditure in the field. Geographical information is a possible predictor of energy expenditure during simulated mountain climbing. Hagiwara et al. predicted the energy expenditure on a treadmill from the total weight, including carrying packs and the up–down vertical transfer velocity [24]. De Müllenheim et al. compared an accelerometer, heart rate monitor, and global positioning system (GPS) and concluded that GPS was the most accurate method for estimating the energy expenditure in outdoor uphill and downhill walking activities [25].

Before measuring the workload of the various tasks undertaken throughout the year by Japanese forestry operations, a simple, accurate, and applicable method for estimating energy expenditure in the field should be clarified. The aim of this pilot study was to investigate which device is most suitable for estimating the energy expenditure during forestry work on inclined ground, as is common in Japan. To achieve this, we selected a physically intensive task in cable operations as the target task, which requires Japanese forestry workers to bring heavy tools and equipment up and down slopes.

2. Materials and Methods

2.1. Participants and Fields

Six male adults, aged 37–63 years, were recruited for this pilot study. They were not forestry workers, but engaged in forestry research and management, and sometimes worked in the field. The protocol was approved by the ethics board of the Japan Organization of Occupational Health and Safety (approval number, 2022-07) in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants. Field measurements were conducted in an unsurfaced test field at the Forestry and Forest Products Research Institute in Tsukuba, Japan, from 17–20 October 2022. We used flat ground and 15°- and 30°-slopes up to a height of 8 m.

The measurement procedure began two hours after breakfast or lunch to minimize the thermal effect of food on the measurement. First, the participants prepared forestry work appurtenances such as work garments, boots, helmets, and gloves (Supplementary Figure S1) and wore portable metabolic analyzers, accelerometers, and heart rate monitors. When the measurements began, they rested on a chair in a large room for 30 min and then moved to the test field at the bottom of the slope. After sitting on a chair until their heart rate and $\dot{V}O_2$ became steady, they shouldered a frame pack of 20 kg on their backs and started walking on flat ground. The weight-simulated packs included devices and tools for cable yarding. The participants could walk at any speed, but in the first 10 s, the researcher let them hear a metronome at a speed of 67/min, which taught them a speed of approximately 50 m/min. They turned at the pylon 185 m from the starting point, returned at the same speed as the starting point (a total of 370 m), unloaded the frame pack, and sat down on a chair. After resting until the monitored heart rate and $\dot{V}O_2$ became steady within 5 min, the participants shouldered the frame pack and started climbing on a 15° slope. They reached their peaks, turned around, and descended. They sequentially repeated the up-and-down procedures three times, unloaded, and rested. They then moved to the bottom of the 30° slope and rested. Next, they climbed and descended the 30° slope three times shouldering the frame pack. After the heart rate and VO_2 stabilized, all devices were removed. The entire procedures took 1.5–2 h, which made it possible to accurately measure the air composition within the battery capacity and maintain the internal device temperature of the portable indirect calorimeter.

2.2. Measurements

2.2.1. Portable Indirect Calorimeter

The metabolic rate was measured using a portable indirect calorimeter, K5 (Cosmed, Albano Laziale, Italy). The K5 sensors were calibrated using a canister syringe for the flow volume and standard gas (16.09% O_2 and 5.01% CO_2) prior to each measurement. During the measurements, the participants wore K5 on their front chest with a mask attached to their face. Data were recorded breath-by-breath and monitored in real-time via Bluetooth in Omnia (Version 2.1, Cosmed, Albano Laziale, Italy) installed on a laptop computer. A K5 with attachments weighed 0.9 kg, which was included in the weight of the frame pack of 20 kg. Oxygen consumption standardized as "standard temperature and pressure, dry (STPD)" was recorded via the device.

2.2.2. Heart Rate Monitor

Heart rate was monitored using Verity Sense (Polar Electro Oy, Kempele, Finland), which weighed 17 g. The device was fully charged, and the inner time was adjusted to the Standard Time daily. The participants attached the device to their non-dominant forearm with an elastic band. Heart rate data for every second (expressed as beats/min) were recorded in the device, which was downloaded to the computer using Polar FlowSync (Version 3.0.0.1337, Polar Electro Oy, Kempele, Finland) on each measurement day. The real-time heart rate was monitored using Bluetooth and K5.

2.2.3. Accelerometer

The participants attached 20 g of the wGT3X-BT with three-axis accelerometric sensors (ActiGraph, Pensacola, FL, USA) to their right waist with an elastic band. The sampling rate was 30 Hz, and we used 1 s epoch counts of acceleration to measure the physical activity. The device was completely charged and adjusted daily. Memorized data were downloaded after each measurement day using ActiLife (Version 6.13.4, ActiGraph, Penacola, FL, USA). The three-axis counts were summarized as vector magnitudes (VM; counts/s).

$$\mathrm{VM} = \sqrt{{c_x}^2 + {c_y}^2 + {c_z}^2} \quad (1)$$

Acceleration counts are used to predict METs and energy expenditure per body mass, and we used a unit "counts" in this study.

2.2.4. Global Navigation Satellite System Device and Video Camera

A global navigation satellite system (GNSS) device, Trimble TDC150 (Nikon-Trimble Co., Ltd., Tokyo, Japan), was used to trace the geographical movements of the participants. Latitude, longitude, and height were recorded in seconds and downloaded from a CSV file. This device, weighing 0.85 kg, was fixed on a frame pack, which weighed 20 kg in total. Participants' behaviors were recorded in the video camera memory to define the time points of events, such as starts, turns, and ends of walking.

2.2.5. Body Height and Weight

Before wearing the devices, body height was measured without boots to 0.1 cm using a stadiometer. Weight was measured with fieldwork clothing and boots (0.1 kg using an electronic scale, AD6201 (A&D Co., Ltd., Tokyo, Japan)). Body weight was calculated by subtracting 3 kg from the measured weight.

2.3. Statsitical Analysis

The intensity of the activity was compared between measurements. For standard activity intensity, the metabolic equivalents of tasks (METs) were calculated from oxygen consumption as follows:

$$\frac{O_2\left(\mathrm{mL{\cdot}min^{-1}}\right)}{body\ weight\ (\mathrm{kg})\ 3.5\left(\mathrm{mL{\cdot}kg^{-1}{\cdot}min^{-1}}\right)} \tag{2}$$

The heart rate index (HRI) was calculated as the mean heart rate during walking divided by the resting heart rate (HR_{rest}), which was defined as the lowest heart rate while the preceding rest was on a chair. Heart rate and oxygen consumption did not reach a steady state during short walking on slopes; they increased after the start and gradually decreased during the following resting period. First, we calculated the cumulative amounts of oxygen consumption and HR exclusively during each of the three walking types because the resting heart rates after walking were not consistent for each participant. Next, we calculated the cumulative heart rate index and oxygen consumption as those during walking plus those in the recovery period after walking, minus the resting amounts. For example,

$$\sum_{\mathrm{sec}}^{walk} \dot{V}O_{walk}(\mathrm{mL/\ sec}) + \sum_{\mathrm{sec}}^{rest} \dot{V}O_{rest}(\mathrm{mL/\ sec}) - \dot{V}O_{rest}(\mathrm{mL/\ sec}) \times Rest(\mathrm{sec}). \tag{3}$$

$$\sum_{sec}^{walk} HRI_{walk} + \sum_{sec}^{rest} HRI_{rest} - HRI_{rest} \times Rest(\mathrm{sec}). \tag{4}$$

The walking periods of the accelerometer data were clearly demarcated, differing only by one or two seconds from the video camera recordings, and the VM during rest was zero. The cumulative vector magnitudes divided by each walking period (counts/min) were compared with the METs calculated from $\dot{V}O_2$.

Each participant received three data points for each activity intensity variable. HRI and VM per minute were examined using Pearson's correlation coefficients, with oxygen consumption as the MET. The Deming regression method was also used for comparison with METs because of possible measurement errors in the two variables [26]. METs estimated from HRI using a previously proposed formula [20] were compared with METs calculated from $\dot{V}O_2$ (Equation (5)) using a Bland–Altman plot [27]:

$$\mathrm{METs} = \mathrm{HRI}\ \times 6 - 5 \tag{5}$$

The GNSS data from the device were compared with the land formation in the test field. The data were expected to obtain work in physics from the vertical transfer and body and appurtenant weights (frame pack, clothing, shoes, and other equipment). However, the vertical movement was not accurately detected; therefore, we did not analyze the GNSS data further. Graphical and statistical analyses were conducted using R (Version 4.2.1, R Core Team, Vienna, Austria) and RStudio (Version 2022.12.0, Posit Software, Boston, MA, USA). The significance level was set at $p = 0.05$.

3. Results

The participant characteristics are presented in Supplementary Table S1. On the first day, there was a small amount of precipitation, and the ground was a little dirty until the second day, when three out of six participants were measured. Three participants were measured in the morning and the other three in the afternoon. The ambient temperature during the measurement was 22–25 °C, and the relative humidity was 53–72%. We missed the GNSS recordings for one participant and video recordings for another participant.

The oxygen consumption (VO_2), heart rate (HR), vector magnitude (VM) of the accelerometer, and vertical (height) movement from the GNSS data were visually compared at the same timescale (Figure 1 and Supplementary Figure S2). The start and end of each activity and rest coincided with the inflection points of $\dot{V}O_2$ and HR. $\dot{V}O_2$ and HR during activity increased in the order of flat, 15° incline, and 30° incline, but VM was not significantly different among the three walking types. Additionally, VM was stable at zero during rest. The height movement clearly depicted up and down transfers, but the baseline was unstable, as observed in all participants. In the following analysis, we used $\dot{V}O_2$, HR, and VM, excluding the height from the GNSS device.

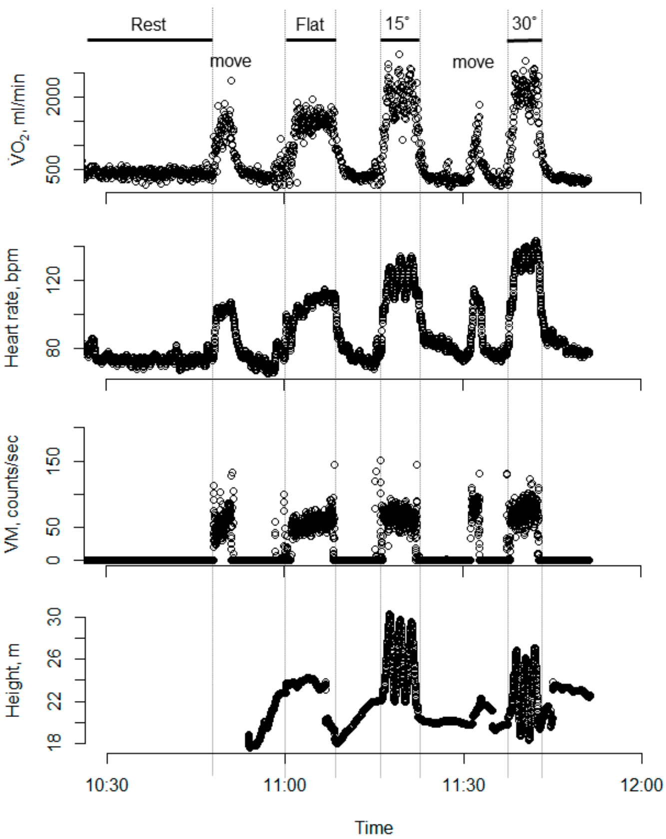

Figure 1. Time-course of measurement variables. From the top to the bottom, oxygen consumption (VO_2; mL/min) in breath by breath, heart rate (beats/min, bpm) in second, vector magnitude (VM; counts/sec) of the accelerometer in one second epoch, and height from the global navigation satellite system device in meter for one participant. The participant walked on flat, 15° and 30° slope grounds after resting on chair. Before walking on flat ground and a 30° slope, the participant moved to each starting point.

The activity intensity as METs calculated from $\dot{V}O_2$ was plotted against HRI and VM (Figure 2). HRI was significantly correlated with METs (r = 0.932, $p < 0.001$), and regression coefficients were 6.38 (95% confidence limits, 4.71, 8.06) for slope and −5.49 (−7.97, −3.02) for intercept. In contrast, VM did not correlate with METs (r = 0.354, $p = 0.150$). The coefficients of its regression model were not significant (0.0012 (−0.0001, 0.0026) for slope, and 0.402 (−4.258, 5.062) for intercept). When involving lag time for $\dot{V}O_2$ and HR, HRI and VM were significantly correlated with METs, but were lower than those measured exclusively during activity (r = 0.843, $p < 0.001$; r = 0.506, $p = 0.032$, respectively).

(**a**)

(**b**)

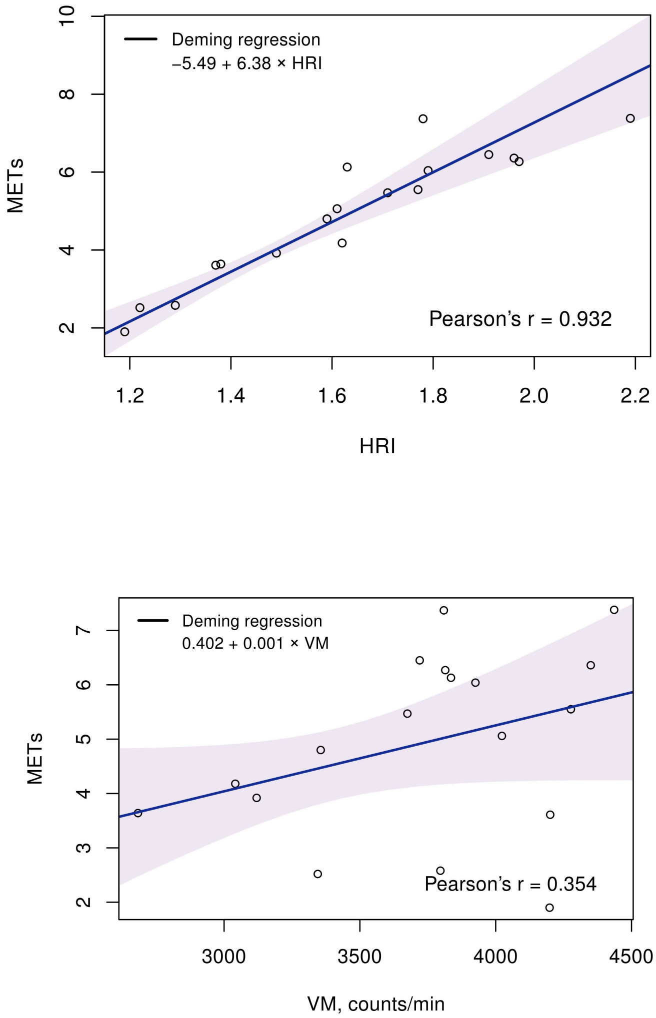

Figure 2. Deming regression models and Pearson's correlation coefficients of activity intensity: (**a**) heart rate index (HRI) and metabolic equivalents of tasks (METs) calculated from oxygen consumption; and (**b**) vector magnitude (VM) of accelerometer and METs from oxygen consumption.

The activity intensities as METs calculated from the Equation (5) and from $\dot{V}O_2$ were plotted using the Bland–Altman method (Figure 3). The difference between the two methods was 0.134 METs with 95% confidence limits, −0.543, and 0.811 METs.

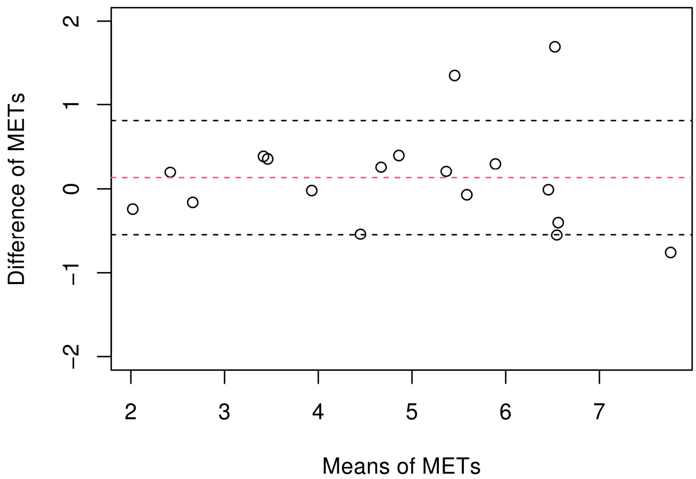

Figure 3. Bland–Altman plot of METs calculated between oxygen consumption and HRI. A red dotted line is the mean difference, and black dotted lines are 95% confidence limits of difference.

4. Discussion

In this pilot study, the HRI method was found to be the best for estimating the energy expenditure rate of forestry workers. We simulated the movement of forestry workers carrying 20 kg on their backs on flat and inclined ground. The activity intensity in METs estimated from HRI using the equation previously proposed by Wicks et al. [20] was significantly correlated with that from the measured oxygen consumption. In addition, most of the estimates were within ±1.0 METs of measured intensity on the Bland–Altman plot.

Heart rate is used to estimate energy expenditure because of its well-known linear relationship, but at a low level of activity, a linear association between heart rate and oxygen uptake O_2 breaks down. The heart rate above which the heart rate is a good predictor of energy expenditure and below which the resting metabolic rate is used as energy expenditure is called the flex heart rate, HR_{flex}. A study of 167 adults proposed that heart rate monitoring is a useful method for assessing energy expenditure in epidemiological studies [28]. Although most participants (70%) from five experimental studies revealed that the total energy expenditure estimated using the flex heart rate method was within ±10% of the standards [29], the flex heart rate and a linear relationship above the flex heart rate are vulnerable to between-individual variation [19,30].

Wicks et al. evaluated the relationship between heart rate and oxygen consumption in exercise training using three variables: absolute HR ($HR_{absolute}$), $HR_{absolute}$ minus HR_{rest} (HR_{net}), and the ratio to resting HR (HRI) [20]. They selected 60 articles involving healthy people and cardiovascular patients whose ages ranged from 27 to 85 years. Among the regression models with three variables, the model with $HR_{absolute}$ explained 76.9% of the variation; however, it was the lowest among the three methods. The model using the HRI had the highest variance explanation R^2 value of 95.2%. The HRI method was validated using treadmill tests for professional rugby and soccer football players [22,23]. HRI is a possible indicator of the intensity of physical activity patterns. The results of this study revealed a high correlation between HRI and oxygen consumption during the simulated walk of forestry workers. Unlike previous reports, in which the workload was applied using a treadmill or cycle ergometry in a well-conditioned room [20,22,23], this study simulated forestry work. The HRI method must be applicable to real forestry fields under various conditions.

Factors influencing heart rate should be considered, such as environmental and genetic factors, and medication. The HR_{flex} method was reviewed by Leonard, who evaluated it under several conditions, including age, sex, ethnicity, season, and lifestyle [31]. Medical condition, particularly using β-blockade, may create problems in field assessment. In a previous report, however, pathophysiological condition and using β-blockade did not affect the relationship between the HRI and the oxygen consumption [20].

At forestry work sites, individual resting HR may be difficult to obtain. Japanese forestry workers usually move between their home and the site and take breaks outdoors, but not in field offices. The HR_{flex} method uses the highest HR for lying or sitting and the lowest HR for activity, and requires individual calibration [18,19]. In contrast, the lowest HR at rest, used to calculate the HRI, may be relatively easy to obtain before work or on breaks. The time course of the HR suggested a shorter resting period before measurement. Calculating HRI, unlike the relative HR, does not require a submaximal heart rate, which may be influenced by age, sex, and fitness.

An accelerometer-based approach for assessing physical motion cannot correctly discriminate activity types in terms of the magnitude proportional to energy expenditure [32,33]. Several trials have been conducted to estimate the energy expenditure from accelerometer data [34]; however, these have not yet been used in the field. Energy expenditure in ascending and descending inclines is not mirror symmetry [24]; oxygen consumption on a −8% descending incline is the least and increases on a more descending incline. Global positioning systems [35], barometric sensors [36], and accelerometry are expected to accurately estimate the energy expenditure. However, in this study, the GNSS receiver could not accurately measure vertical movements of 8 m up and down. This device had no barometric sensors, but the portable indirect calorimeter K5 had them. However, even the barometric altitude at K5 was unstable during each measurement.

A heart rate monitor is a light device that may place a slight burden on the participants. The device used in this study is worn with an arm strap attached to the forearm or upper arm. It may be more applicable in forestry fields than chest-strapped ones because there is no need to take off clothes, and it may not disturb the use of hand tools as much as a wrist-worn monitor. Regarding where the monitor is worn, the accuracy of various forestry tasks is warranted in the future [37]. Some conditions that influence the HR should be considered. First, although it can estimate high workloads in forestry activities, HR during periods of low workload and recess may be influenced by non-work-related factors when considering daily work. We need to determine the energy expenditure specific to hard forestry work. Knowledge of the workload regarding energy expenditure can help us properly allocate jobs to workers, deploy workers for their fitness, and prevent heat illness by predicting thermogenesis from the workload. Second, terrain surface conditions influence the energy cost [38], but this factor may not influence the relationship between HR and oxygen consumption. Third, in some studies, such as felling, pruning, and mowing, upper limb activity is considered the main cause of energy expenditure. In contrast to motion sensors and GNSS devices, HR monitoring, as an estimator of energy expenditure, has advantages for forestry workers.

This study has some limitations regarding the interpretation and adoption of the results in the field. First, the sample consisted of only male participants and the sample size was small. However, male workers were dominant in Japanese forestry, and the age of the participants varied widely. The results of the association between heart rate and metabolic rate were in accordance with a previous formula [20]. Several studies have reported small sample sizes in actual forestry fields (5–13 participants) [10–13]. A low risk of a statistical type 2 error due to small sample size, which indicates a small measurement error in correlation, may be a strength for implementing the main study. Second, the test field was not the same as the forestry field. Forestry activities are a combination of complicated motions, rather than walking. We did not have information on how and when heart rate monitoring was interrupted during forestry work activities due to loss of contact with the skin. For one participant, the heart rate decreased to zero when the weights were pulled down, and the elastic band of the monitor was soon tightened.

5. Conclusions

The HRI method was the best estimator of METs, similar to the energy expenditure rate in this pilot study. Accelerometry was insufficient to discriminate between activity types, and estimated energy expenditure less efficiently than the HRI method. The GNSS device did not accurately trace the vertical (height) movements; therefore, the work in physics could not be calculated. The HRI method uses a light device to monitor HR, which imposes only a small burden on forestry workers in the field. The arm-worn HR monitor used in this study is more convenient for forestry workers in the field because they do not have to wear a chest strap under their shirt. Simultaneous and repeated measurements using a low-cost device by a team of forestry workers will provide valuable information about various forestry tasks throughout the year. This study bridges the gap between laboratory settings and HRI. The HRI method can be used to estimate the workload in forestry work and can present the workload of each forestry task and activity as a physical activity level (MET) in future studies in the field. MET as a common unit will be practical in the prevention of fatigue and injury, healthy behavior related to energy and nutrition intake, and heat-related illness.

Supplementary Materials: The following supporting information can be downloaded from: https://www.mdpi.com/article/10.3390/f14051038/s1, Table S1: Characteristics of the participants; Figure S1: Participants during the measurement; Figure S2: Time course of measurement variables of other participants.

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References

1. International Labour Office. *Safety and Health in Forestry Work: An ILO Code of Practice*; International Labour Office: Geneva, Switzerland, 1998.
2. Ministry of Health Labour and Wealfare. Sen-nin-Ristsu. Available online: https://anzeninfo.mhlw.go.jp/user/anzen/tok/anst00.htm (accessed on 15 December 2022).
3. Lilley, R.; Feyer, A.M.; Kirk, P.; Gander, P. A survey of forest workers in New Zealand. *J. Saf. Res.* **2002**, *33*, 53–71. [CrossRef] [PubMed]
4. Bowen, J.; Hinze, A.; Griffiths, C. Investigating real-time monitoring of fatigue indicators of New Zealand forestry workers. *Accid. Anal. Prev.* **2019**, *126*, 122–141. [CrossRef] [PubMed]
5. Hinze, A.; Konig, J.L.; Bowen, J. Worker-fatigue contributing to workplace incidents in New Zealand Forestry. *J. Saf. Res.* **2021**, *79*, 304–320. [CrossRef] [PubMed]
6. Lundbäck, M.; Persson, H.; Häggström, C.; Nordfjell, T. Global analysis of the slope of forest land. *For. Int. J. For. Res.* **2020**, *94*, 54–69. [CrossRef]
7. Japan for Sustainability. about the Condition of Japanese Forests. Available online: https://www.japanfs.org/en/news/archives/news_id027771.html (accessed on 15 December 2022).
8. Kühmaier, M.; Stampfer, K. Development of a multi-attribute spatial decision support system in selecting timber harvesting systems. *Croat. J. For. Eng. J. Theory Appl. For. Eng.* **2010**, *31*, 75–88.
9. Eroglu, H.; Yilmaz, R.; Kayacan, Y. A study on determining the physical workload of the forest harvesting and nursery-afforestation workers. *Anthropology* **2015**, *21*, 168–181. [CrossRef]
10. Spinelli, R.; Aalmo, G.O.; Magagnotti, N. The effect of a slack-pulling device in reducing operator physiological workload during log winching operations. *Ergonomics* **2015**, *58*, 781–790. [CrossRef]
11. Arman, Z.; Nikooy, M.; Tsioras, P.A.; Heidari, M.; Majnounian, B. Physiological workload evaluation by means of heart rate monitoring during motor-manual clearcutting operations. *Int. J. For. Eng.* **2021**, *32*, 91–102. [CrossRef]
12. Sibiya, Z.B.; Ackerman, P.; Ackerman, S.A. Productivity and workload analysis between manual and motor-manual pruning of Pinus patula at two different lifts. *Int. J. For. Eng.* **2021**, *32*, 191–201. [CrossRef]
13. Grzywiński, W.; Turowski, R.; Jelonek, T.; Tomczak, A. Physiological workload of workers employed during motor-manual timber harvesting in young alder stands in different seasons. *Int. J. Occup. Med. Environ. Health* **2022**, *35*, 437–447. [CrossRef]
14. Masci, F.; Spatari, G.; Bortolotti, S.; Giorgianni, C.M.; Antonangeli, L.M.; Rosecrance, J.; Colosio, C. Assessing the Impact of Work Activities on the Physiological Load in a Sample of Loggers in Sicily (Italy). *Int. J. Environ. Res. Public Health* **2022**, *19*, 7695. [CrossRef] [PubMed]
15. Yoshikawa, M.; Numata, K. Physiological analysis on walking burden in forestry operations. *J. Jpn. For. Soc.* **2001**, *83*, 279–284. [CrossRef]
16. Itou, T.; Yamada, Y. Analysis of workload and weed suppression effects from changing the brush-cutting season. *J. For. Soc.* **2001**, *83*, 191–196. [CrossRef]
17. Kajitani, H.; Kjisa, T. Work recognition using physical stress level and motion analysis in forestry labor. *J. For. Eng. Soc.* **2020**, *35*, 45–52.
18. Spurr, G.B.; Prentice, A.M.; Murgatroyd, P.R.; Goldberg, G.R.; Reina, J.C.; Christman, N.T. Energy expenditure from minute-by-minute heart-rate recording: Comparison with indirect calorimetry. *Am. J. Clin. Nutr.* **1988**, *48*, 552–559. [CrossRef] [PubMed]

19. Livingstone, M.B.; Prentice, A.M.; Coward, W.A.; Ceesay, S.M.; Strain, J.J.; McKenna, P.G.; Nevin, G.B.; Barker, M.E.; Hickey, R.J. Simultaneous measurement of free-living energy expenditure by the doubly labeled water method and heart-rate monitoring. *Am. J. Clin. Nutr.* **1990**, *52*, 59–65. [CrossRef] [PubMed]
20. Wicks, J.R.; Oldridge, N.B.; Nielsen, L.K.; Vickers, C.E. HR index—A simple method for the prediction of oxygen uptake. *Med. Sci. Sport. Exerc.* **2011**, *43*, 2005–2012. [CrossRef] [PubMed]
21. Dube, P.A.; Imbeau, D.; Dubeau, D.; Auger, I.; Leone, M. Prediction of work metabolism from heart rate measurements in forest work: Some practical methodological issues. *Ergonomics* **2015**, *58*, 2040–2056. [CrossRef] [PubMed]
22. Colosio, A.L.; Pedrinolla, A.; Da Lozzo, G.; Pogliaghi, S. Heart rate-index estimates oxygen uptake, energy expenditure and aerobic fitness in rugby players. *J. Sport. Sci. Med.* **2018**, *17*, 633–639.
23. Colosio, A.L.; Lievens, M.; Pogliaghi, S.; Bourgois, J.G.; Boone, J. Heart rate-index estimates aerobic metabolism in professional soccer players. *J. Sci. Med. Sport* **2020**, *23*, 1208–1214. [CrossRef]
24. Hagiwara, M.; Yamamoto, M. Systematic evaluation of the phsyiological load of mountain climbing from the relation between inclination of walking path, walking speed, and backpack weight: Simulation using walking on a treadmill. *J. Phys. Fit. Sport. Med.* **2011**, *60*, 327–341. [CrossRef]
25. De Müllenheim, P.Y.; Chaudru, S.; Emily, M.; Gernigon, M.; Mahé, G.; Bickert, S.; Prioux, J.; Noury-Desvaux, B.; Le Faucheur, A. Using GPS, accelerometry and heart rate to predict outdoor graded walking energy expenditure. *J. Sci. Med. Sport.* **2018**, *21*, 166–172. [CrossRef] [PubMed]
26. Cornbleet, P.J.; Gochman, N. Incorrect least-squares regression coefficients in method-comparison analysis. *Clin. Chem.* **1979**, *25*, 432–438. [CrossRef] [PubMed]
27. Bland, J.M.; Altman, D.G. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* **1986**, *8476*, 307–310. [CrossRef]
28. Wareham, N.J.; Hennings, S.J.; Prentice, A.M.; Day, N.E. Feasibility of heart-rate monitoring to estimate total level and pattern of energy expenditure in a population-based epidemiological study: The Ely Young Cohort Feasibility Study 1994-5. *Br. J. Nutr.* **1997**, *78*, 889–900. [CrossRef]
29. Livingstone, M.B. Heart-rate monitoring: The answer for assessing energy expenditure and physical activity in population studies? *Br. J. Nutr.* **1997**, *78*, 869–871. [CrossRef]
30. Panter-Brick, C.; Todd, A.; Baker, R.; Worthman, C. Comparative study of flex heart rate in three samples of Nepali boys. *Am. J. Hum. Biol.* **1996**, *8*, 653–660. [CrossRef]
31. Leonard, W.R. Measuring human energy expenditure: What have we learned from the flex-heart rate method? *Am. J. Hum. Biol.* **2003**, *15*, 479–489. [CrossRef]
32. Hendelman, D.; Miller, K.; Baggett, C.; Debold, E.; Freedson, P. Validity of accelerometry for the assessment of moderate intensity physical activity in the field. *Med. Sci Sport. Exerc.* **2000**, *32*, S442–S449. [CrossRef]
33. Bassett, D.R., Jr.; Ainsworth, B.E.; Swartz, A.M.; Strath, S.J.; O'Brien, W.L.; King, G.A. Validity of four motion sensors in measuring moderate intensity physical activity. *Med. Sci. Sport. Exerc.* **2000**, *32*, S471–S480. [CrossRef]
34. Chen, K.Y.; Bassett, D.R., Jr. The technology of accelerometry-based activity monitors: Current and future. *Med. Sci Sport. Exerc.* **2005**, *37*, S490–S500. [CrossRef] [PubMed]
35. Troped, P.J.; Oliveira, M.S.; Matthews, C.E.; Cromley, E.K.; Melly, S.J.; Craig, B.A. Prediction of activity mode with global positioning system and accelerometer data. *Med. Sci. Sport. Exerc.* **2008**, *40*, 972–978. [CrossRef] [PubMed]
36. Wang, J.; Redmond, S.J.; Voleno, M.; Narayanan, M.R.; Wang, N.; Cerutti, S.; Lovell, N.H. Energy expenditure estimation during normal ambulation using triaxial accelerometry and barometric pressure. *Physiol. Meas.* **2012**, *33*, 1811–1830. [CrossRef] [PubMed]
37. Gillinov, S.; Etiwy, M.; Wang, R.; Blackburn, G.; Phelan, D.; Gillinov, A.M.; Houghtaling, P.; Javadikasgari, H.; Desai, M.Y. Variable accuracy of wearable heart rate monitors during aerobic exercise. *Med. Sci. Sport. Exerc.* **2017**, *49*, 1697–1703. [CrossRef]
38. Soule, R.G.; Goldman, R.F. Terrain coefficients for energy cost prediction. *J. Appl. Physiol.* **1972**, *32*, 706–708. [CrossRef]

令和４年度　産業保健調査研究
－林業従事者の傾斜地作業負荷測定方法開発のためのパイロット研究－

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