HOW ACCURATE AND BIASED IS SLOPE PERCEPTION OF SNOW-COVERED MOUNTAINS?

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ABSTRACT: Estimating the slant of a snow-covered mountain slope is a difficult task. Human perception is tailored for accurate perception of cardinal orientations but is less precise for oblique angles. Indeed, previous studies found that humans overestimate the steepness of slopes (Proffitt et al., 1995, 2001). Accurate estimation of the slant of snow-covered mountains is key to identify avalanche release zones, i.e. snow-covered slopes between 30 and 45 degrees that can be start zones for avalanches. We here investigated the accuracy of slope estimation among backcountry skiers varying in experience (study 1, Kattfjordeidet study) and whether training and feedback by using clinopoles can improve accuracy (study 2). In study 1, participants estimated the slant as line-of-sight upwards or sideways from a parking lot. We found that most backcountry skiers overestimated the slant, but the overestimation was less pronounced the more experience the skier has. The overestimation was strongest for shallower slopes. In study 2 we equipped backcountry skiers with clinopoles and asked them to estimate and thereafter to measure slants during their trip, either as line-of-sight upwards, sidewards, downwards, or as contact. Here, we did not find overestimation for shallow slopes but slight underestimation for slopes above 30 degrees. Participants' estimates improved with repeated practice, particularly for contact measurements but less so for line-of-sight measures. Confidence in one's own estimate did not change with practice and was rather idiosyncratic. Our data replicates the classic overestimation bias when skiers use a static estimation method and line-of-sight upwards estimation. This bias was most pronounced for shallower slopes (below 30 degrees) and reduced (study 1) or reversed (study 2) for slopes over 30 degrees. We discuss implications for avalanche safety and education.

KEYWORDS: inclinometer, inclination measurement, avalanche education, backcountry skiing, cognitive bias.

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1. INTRODUCTION

Backcountry behaviour is mainly learned in practice, observing what more experienced people do, and doing it after them. One of the basic things to learn is the role of slope angle in avalanche triggering. In avalanche terrain, knowing the actual slope angle is crucial. Guides and backcountry ski/board instructors operate mainly in very familiar terrain, almost their own backyard, where they know every slope inclination and the regular avalanche paths. They don't need to do inclinometry to lead the group of newbies safely. The experienced instructors can also estimate the slope angles rather accurately. This all results in that aspiring backcountry travellers very seldom observe anybody doing inclinometry. It is also not part of most avalanche courses. Reviewing textbooks, only one of the textbooks emphasized that doing inclinometry regularly improves one's slope estimation skills, two recommend having an inclinometer and develop the estimation skills, others are vaguer or only briefly mention that it is handy to have an inclinometer to measure slope angles. Unsurprisingly, only few backcountry (BC) skiers have a slope inclinometer. However, it is known that regular skills training, make one better at the skill and can become a habit (Bosse et al., 2015).

Inclinometry seems to be left as part of the liturgy, being mentioned but without stating when and where and for whom it would be vitally important. We are convinced that it can be taught. Slope angle estimation is difficult but an attainable skill, that should be performed often on tours (McCammon, 2023).

Previous studies on estimating the slope of hills, both in real and in virtual environments, and when viewed from the side as well as when viewed as line-of-sight upwards found that people overestimate the slant (Proffitt 1995, Proffitt et al., 2001). Hills also appear steeper when wearing a backpack, when participants are fatigued (Bhalla and Proffitt, 1999). However, less is known how people judge steepness of a) snow-covered mountains, b) estimate slope during physical activity, and c) whether estimation improves with practice.

Here we present two studies. In the first study participants estimated the slant as line-of-sight upwards or sideways from a parking lot. This was part of the Kattfjordeidet 'civilian-skier' study (Ahonen et al., 2024). This replicates previous findings of an overestimation bias. In the second study, participants were equipped with clinopoles, and practiced slope estimations and measurements. No overestimation bias was found.

The studies were approved by the Norwegian Agency for Shared Services in Education and Research (SIKT, former NSD) in 2018. The survey tool Qualtrics (Qualtrics, Provo, UT) was used in both studies except the Finnish sample (paper notes). If the estimation is larger than the true value (study 1) or measurement (study 2) this will result in a positive difference and referred to as overestimation bias. Conversely, judging a slope as less steep than it actual is, is referred to as underestimation bias and seen as a negative value in the figures.

2. KATTFJORDEIDET STUDY: ESTIMATING SLANT FROM PARKING SPOT

2.1 <u>Methods and participants</u>

A detailed description of the study can be found in Ahonen et al. (2024). Briefly, participants were recruited at the parking lot to fill out a log after their self-chosen tour on Kattfjordeidet, a popular backcountry area in Troms municipality. We used two parking lots, and on each there was a viewing apparatus built by the authors to standardise skier estimates of two nearby mountain slopes. In parking lot A, one slope was 32.4° and the other was 24°. In parking lot B, one slope was 35.7° and the other one 22°. There were 237 participants that took part in spring 2023, for 114 participants we had valid data for slope angle estimation and or relevant demographic variables.

2.2 <u>Procedure</u>

After answering the log items, participants were guided outwards to look at the mountains and then provide a numerical estimate of steepness, and an uncertainty range.

2.3 <u>Results</u>

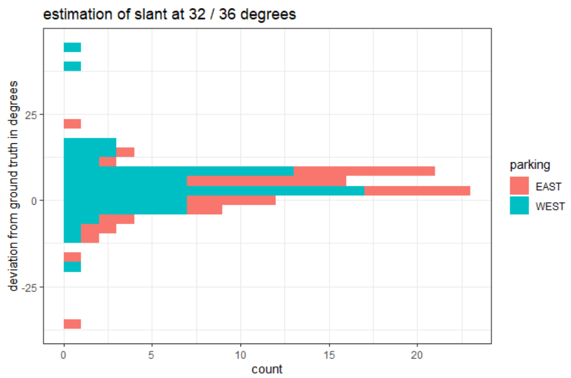
Most participants overestimated the steepness (Fig 1a, 1b). For shallower slopes (22° or 24°) the average overestimation was 5.68°. For steeper slopes (32° or 36°) overestimation was on average 3.61°. This difference was not stastistically significant, Welch's $t(205.58) = -1.68$, $p = .095$, Cohen's $d = .23$.

Among those participants for whom we had demographic data ($n = 107$, Figure 1c), we found that less experienced BC skiers overestimated the slope more than more experienced BC skiers, $F(3,53) = 2.377$, $p = .08$. Compared to the less-than-two-years of experience group ($n = 14$), the group with more than 10 years of experience ($n = 41$) had a significantly lower bias, $\beta = -5.98$, $t = -2.54$, $p = .014$; the group with between 6 to 10 years of experience ($n = 30$) had a significantly lower bias, $\beta = -5.57$, $t = -2.01$, $p = .049$; and the group with between 2 to 5 years experience ($n = 22$) had a non-significantly lower bias, $\beta = -5.3$, $t = -1.92$, $p = .061$.

For the slope above 30 degrees, 44% included the true value in their uncertainty range. For the slope below 30 degrees, 31% included the true value in their uncertainty range. Only 16 participants included the true value in both estimations. Overall, in 62% of the cases the true value was not included when taken the uncertainty range of the participant into account.

That is, the true slope degree falls outside what the participant considers as likely.

A.



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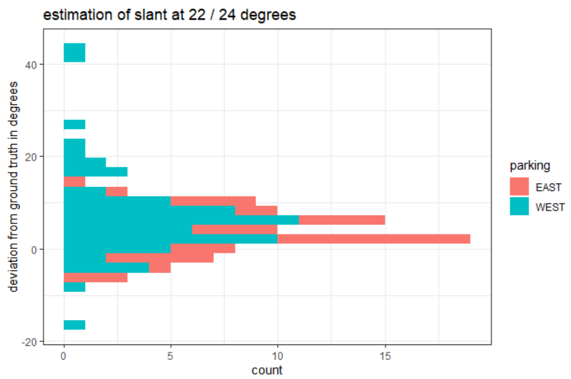

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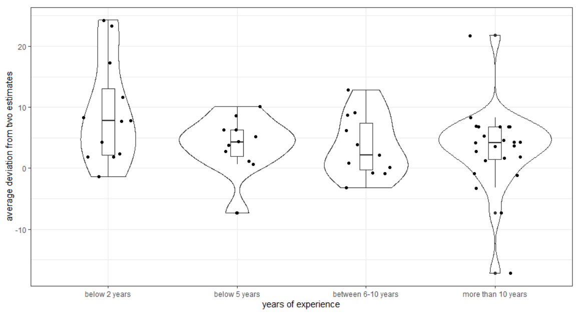

Figure 1. **panel A**: estimation of a slant "above 30 degrees", **panel B**: estimation of a slant "below 30 degrees", from the two different parking lots. **Panel C**: Less overestimation of the slant with experience. Dots represent individual participants. Horizontal black line is the median and boxes indicate the interquartile range.

3. CLINOPOLE: PRACTICING SLANT ESTIMATION DURING A SEASON

3.1 Methods and participants

In the Finnish sample, 10 participants (age range 30 to 50; 3 women) were recruited by personal contact. The 10 skiers varied in their BC experience from 1 year (approximately 15 days with BC skiing) to over 20 years and around 900 days accumulated with BC skiing. They did two to six backcountry tours and on each tour, they did five to 12 slope angle estimations followed by inclinometry. They recorded the results and time of the procedure on their first and last tours.

In the Norwegian sample, 36 participants (age range 23-59, 14 women) were recruited by personal contact and social media. 25 took part in the practical session. 13 (4 women) answered the post-survey. Among the 13 participants, two had avalanche forecaster training, one had avalanche instructor training, two took part in an advanced recreational avalanche course, seven took a basic recreational avalanche course and one indicated no avalanche course or education. One indicated expert skills in mitigating avalanche danger, nine indicated moderate skills, two basic skills and one limited skills. All indicated at least basic ski riding skills (basic: n = 3, moderate: n = 6, advanced: n = 3, expert: n = 1). They had from one to 27 years of backcountry experience, and in a typical season would spend between 12 and 50 days backcountry skiing. None of them was familiar with Clinopoles or measured regularly inclination. Some mentioned knowing digital inclinometers.

Prior to the study, all participants handed in their ski poles to be fitted with the inclinometry tool '*Clinopole*'. The Clinopole tool consists of a set of stickers and spirit level mounted to the poles, affording the user measures of both the angle of the slope underneath (contact inclinometry) as well as slopes above or below the point of standing, or horizontally further away (line of sight). More information regarding the tool of use can be found at http://mattiverkasalo.wixsite.com/instantinclinometry

3.2 Procedure

For the Norwegian sample we offered a workshop where they received instructions on the use of the inclinometry tool, as well as practice with the possibility of feedback and clarifications. The workshop took place on a local hill where the participants got to practice measuring slope angles of snow-covered slopes. The use of all types of measures (contact inclinometry and line of sight in all three directions) were demonstrated by the author KE, followed by time for practice as well as instructions to ensure understanding. Participants were encouraged to estimate slopes and measure them afterwards with the clinopoles during each self-chosen backcountry trip.

When recording a measure whilst in the mountains, the participants were first asked to individually estimate the steepness of the slope to be measured. The angle was entered into the application, followed by a score of confidence regarding the accuracy of the estimation (0° to ± 5°). The same slope angle was then to be measured using the specific part of the inclinometry tool, and the measured angle entered in the application along with which type of measurement had been used. Participants were encouraged not to conduct estimates and measures on the same slope, but to vary the areas to be measured. The participants were encouraged to conduct further estimations – measures of slope angles in addition to the ones recorded in the app – to repeat the process of visual estimation and feedback by measure.

3.3 <u>Results</u>

In the Finnish sample, of the 10 participants, nine reduced their error, i.e. their estimated slope converged towards the measured slope (Figure 2a), but they still misestimated by one to four degrees. Four only performed contact measurements. The time required for contact inclinometry diminished from 20 to 9 seconds and for line-of-sight inclinometry from 14 to 7 seconds over the study.

In the Norwegian sample six of the 13 participants answering the post survey indicated having used the Clinopoles on more than 10 backcountry tours. Pooled among all reported estimations (n = 324) and measurements there was no overestimation bias. However, separating by type of measurement and whether the actual slope was less / equal than 25 degrees (n = 157), between 26 and 30 degrees (n = 109), or above 30 degrees (n = 58) showed that there was a) overestimation for line-of-sight upwards, b) underestimation for line-of-sight sideways, c) shallower slopes are not more overestimated whereas steeper slopes are more likely underestimated, $F(5, 318) = 5$, $p < .001$, see Figure 2b. However, a closer inspection showed that the over- and underestimation was due to one participant touring in June (see Figure 2c). Still, underestimation for steeper slopes was evident across the season.

We next tested whether the uncertainty range covers the measured value. For contact the true value was included in 64% of estimations. For line-of-sight downwards / upwards / sideways the true value was included in 58% / 71% / 58%, respectively.

Finally, we asked for satisfaction with the Clinopoles. Three mentioned that it is cumbersome to use and likely imprecise. One stated that the contact measurement is easy, but the line-of-sight were more challenging to perform. Four found it easy to use and one mentioned that it contributes to avalanche terrain awareness. Overall, two participants were very satisfied, five were satisfied and five were indifferent. Three planned using the Clinopoles the next season.

4. DISCUSSION

In study 1 we replicated a common finding that people overestimate slopes (Proffitt et al., 1995, Proffitt et al., 2001) and err on the too steep side. However, a closer look showed that the bias was more pronounced for the shallower than the steeper slope. In study 2 we found that practice improved the

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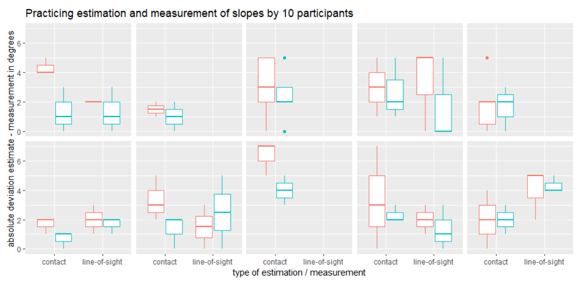

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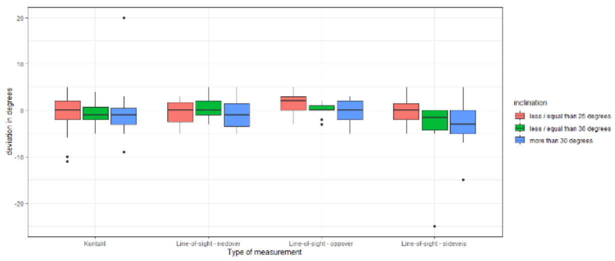

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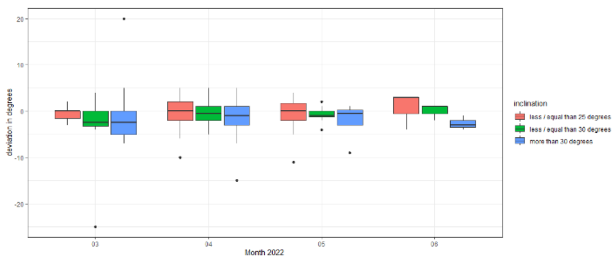

Figure 2. **panel A**: reduction of misestimation with practice, Finnish sample. Red denotes the first and blue the last tour, separate for each of the 10 participants. **Panel B**: Estimation and measurement with Clinopoles reveals underestimation bias for slopes steeper than 30 degrees. **Panel C**: Overestimation of shallower slopes and underestimation of steeper slopes occurs late in the season driven by a single user. The estimation and measurement is done by the same person, no ground truth.

estimation (Finnish sample). In contrast to study 1 we did not find that shallower slopes were overestimated as steeper. There was rather underestimation of steeper slopes, i.e., they were generally judged as less steep. The 30° is taught as a "threshold", i.e., it is safe to go backcountry skiing on slopes below 30 degrees even if the danger level is above 1. Inasfar this "threshold" influences peoples estimation remains to be seen. We refrain from interpreting the underestimation as steeper slopes wanting to appear safe as our sample size is too small and likely not representative. Furthermore, we do not know whether the measurement affected to ascent/descent or turn from the slope. However, teaching a "below 30 degree it is safe rule" may implicitly affect estimation and measurement, which requires further research. More data is needed for slopes above 35°, challenging ethical considerations.

In both studies the error was below 4° for slopes above 30 degrees, but higher for shallower slopes. The 4° margin aligns well with McCammon's (2023) stipulation that accuracy comes with an ± 4° error. In study 1 only few participants made large enough uncertainty estimates. We do not know whether this is due to the format of how we asked for it – we provided only a range from 0° to ± 5° which may anchor them to using small values – or overconfidence in one's skills (Kruger & Dunning, 1999).

There are limitations to our studies. In study 1 we did not have demographic data for all participants and could not control for weather and visibility conditions as testing occurred outdoors at multiple days, at different time points of the day, and after participants did a BC trip and filled out the log. Besides different visibility conditions, fatigue and motivation may also affect the results (Dean et al., 2016). We also have no information of whether they practice slope estimation. In study 2 we have many measurements per participant but we do not know when (beginning, half-way or at the end) at a tour they estimated and measured it, nor what their decision was (go/nogo). We encouraged regular use, and at different time points / occasion by asking for contact, sideway, upwards and downward estimation. However, due to the ease of the contact measurement, most data is contact, and least was done as line-of-sight downwards. This may reflect the perceived larger effort and only highly motivated participants engaged in this activity (Mækelæ et al., 2023, Proffitt et al., 2003). Furthermore, due to not informing participants to update the offline Qualtrics version (Norwegian sample only), the registration of the estimation and measurements could not be linked with the post-survey data. Crucially, the measurement with the inclinometer comes itself with uncertainty and does not represent the ground truth (McCammon, 2023). Measurements with the clinopoles rely on the correct usage and ability to read of the slope angle. We did not find a systematic bias in our data, however, we cannot rule out that participants read of a number that is closer to their estimate than it really was.

Our results support that cognitive rather than perceptual factors contribute to slant estimation (Dean et al., 2016).

We let students in our EiT course (Pfuhl & Engen, 2024) estimate alone and then discuss the same slope. The groups of four to five people converged to the true estimate. Similarly, Dassler et al. (2024) found "wisdom of the crowds". Since BC skiing is often done in groups, independent estimation follwed by discussion could increase accuracy.

In sum, we find that overestimation is less pronounced for steeper slopes, and experience does reduce estimation bias. We encourage demonstrating slope estimation and measurements in avalanche courses and practicing it - thereby reducing cognitive biases and letting perception win (Dean et al., 2016). Knowing how steep a slope is can increase avalanche awareness and focusing on "why is it safe" (Landrø, 2021).

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