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Cognitive characteristics of navigational map use by mountaineers

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ABSTRACT
This study examined the cognitive characteristics of navigational map use by mountaineers. Questionnaires regarding navigation skill and behavior were completed by 362 mountaineers and contour tasks by 155 mountaineers, who participated in a practical course on mountaineering skills. A confirmatory factor analysis of the questionnaire confirmed three cognitive components of map use: Carrying and reference to map and compass; Symbol understanding and Solution of navigational tasks. The score of each cognitive component and the contour tasks differently improved with map-use experience. Gender difference was obtained only in the Line-of-sight task. Another confirmatory factor analysis of questionnaire and contour tasks showed good fit. Contour interpretation skills strongly explained the Navigational map use, which was the second factor from the above three components. The results suggest: (a) contour interpretation is a multifaceted cognitive task consisting of two-dimensional pattern recognition and three-dimensional transformation, (b) map-use skills consist of problem-solving of navigation in addition to basic understanding of map symbols and (c) even the mountaineers with long experience do not necessarily acquire full skills of contour interpretation but solve navigational problems with available cognitive skills, which were acquired in the constraint of the environment.

RÉSUMÉ
Cette étude a examiné les caractéristiques cognitives de l'utilisation de cartes d'orientation utilisées par des alpinistes. Des questionnaires portant sur les compétences en orientation et sur les comportements ont été remplies par 362 alpinistes, et 155 alpinistes ont réalisé une tâche 'courbe de niveau' pour estimer leur aptitude à comprendre les courbes de niveaux. Une analyse factorielle confirmatoire du questionnaire a confirmé trois composantes cognitives de l'utilisation de cartes : Transporter et se référer à une carte et une boussole ; la compréhension des symboles ; Capacité à s'orienter. Le score de chaque composante cognitive et les tâches de lecture de courbes de niveau sont améliorés de façon indépendante en fonction de l'expérience d'utilisation de cartes. Les différences de genre se sont uniquement vue pour la tâche 'ligne de vue'. Une autre analyse factorielle confirmatoire du questionnaire et de la tâche 'courbe de niveau' a montré une bonne correspondance. Les

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compétences en interprétation des courbes de niveau expliquent fortement l'utilisation des cartes d'orientation qui était le deuxième facteur des trois composantes nommées précédemment. Les résultats suggèrent que a) l'interprétation de courbes de niveaux est une tâche cognitive multi-facettes qui consiste en la reconnaissance de pattern à deux-dimensions puis la transformation en trois dimensions b) les compétences en lecture de carte additionne une résolution de problème d'orientation à une compréhension simple des symboles de la carte et c) même les alpinistes ayant une grande expérience n'acquièrent pas systématiquement les compétences complètes d'interprétation de courbes de niveaux mais arrivent à résoudre le problème d'orientation grâce à leurs compétences cognitives acquises dans les contraintes de l'environnement.

1. Introduction

Among many purposes maps serve, the most frequent one in everyday life is navigation. The ability to navigate using maps is particularly important for outdoor activities in order not to get lost. Relatively high rates of accidents involving getting lost in the mountains are reported in Japan (Japanese National Police Agency, 2009; Murakoshi, Watanabe, Higashi, & Takashima, 2010), in Scotland (Sharp, 2001), and in North America (Farabee, 2005). These rates of getting lost, however, represent only the tip of the iceberg. Approximately 15% of the mountaineers in Japan reported that they experienced getting lost at least once within the previous one year (Murakoshi, 2000) and getting lost accidents are attributed to poor navigation skills.

Psychological studies have found that adults even at the formal operational stage (Inhelder & Piaget, 1958), who might possess the cognitive basis necessary for understanding and using maps, are prone to errors when they navigate in a natural setting. University students with little experience using maps made an average of more than one error while navigating a 3–4 km suburban route (Sakurai & Ohta, 2008; Sakurai, Ota, Togashi, & Ueji, 2006). On average, 1.75 errors were made on a trail that involved 10 junctions within a nature park, and approximately one-quarter of the participants made more than three errors (Soh & Smith-Jackson, 2004). Even on a university campus, participants made 11 goal errors and 21 route errors in 72 trials (Warren & Scott, 1993). Although these studies analyzed the cause of errors from environmental factors, or factors related to maps, they did not report individual differences or cognitive characteristics of the map users. Investigating such factors of map use in natural settings is important not only for understanding the characteristics of navigational map use in natural settings but also for contributing to improving the navigation skills of mountaineers. Before clarifying the aims of the current study, the cognitive processes of navigation using maps and contour interpretation are briefly reviewed.

1.1. Cognitive process of navigation and navigational map use

Although quite a few experimental studies concerning map use have been conducted within the framework of cognitive cartography and cognitive psychology, with a focus on how map users acquire and remember information from maps (e.g. Chan & Antes, 1987; Gilhooly, Wood, Kinnear, & Green, 1988; Thorndyke & Stasz, 1980), studies of navigational map use, especially in natural environments, have been very few (Blades & Spencer, 1987; Newcombe, 2002), with the exception of developmental studies (for a review, see Lobben, 2004; Matthews, 1992; Ottosson, 1988).

Navigation is defined as organisms' coordinated and goal-directed movement through an environment, involving the planning and execution of movements (Montello, 2005). The psychological processes of navigation were identified by speculation (Oatley, 1977; Pick et al., 1995; Warren, 1994) or by the qualitative analysis of navigational experts (Brosset, Claramunt, & Saux, 2008; Eccles, Walsh, & Ingledew, 2002). Navigation involves several subtasks, such as searching for appropriate routes to destinations, reading characteristics of a route (e.g. distance, direction and landmarks), determining one's location on a map, and maintaining a planned route. They were summarized into three subtasks of navigation in a practical textbook for navigational map use (Department of the Army, 2004) as follows: knowing where one is located (determination of one's position, or self-location), planning the route, and remaining on the route.

Of the subtasks, self-location is regarded as a problem-solving act (Lobben, 2004) and the key for navigational success (Lobben, 2007). Although self-location is not an easy task even in a simple environment (Liben, Myers, & Kastens, 2008), it is more difficult in natural terrain where distinct landmarks are insufficient and associating maps to the environment is difficult. In such environments, generation and evaluation of multiple hypotheses about the current location through a disconfirmation procedure are necessary (Pick et al., 1995). The evaluation of multiple hypotheses during self-location was also identified in a study of eye movement (Murakoshi, 1988).

Remaining on the route is also important for successful navigation in natural environments where paths are ambiguous and navigators are apt to deviate from planned routes. In order to remain on the route, the navigators rely on either compass direction or salient landmarks. In the latter case, remaining on the route is often better achieved by map alignment. In urban environments, alignment is typically completed by relating symbols on a map to salient landmarks but a compass is essential for aligning a map in natural environments, where few salient features exist. The importance of alignment was also stressed in a practical field navigation textbook (e.g. Department of the Army, 2004).

Supposing that navigation is such complicated task, navigational map use might demand more cognitive skills than mere symbol understanding and knowledge acquisition from maps. Task demand for navigation and the cognitive components necessary for navigational problem-solving should be considered when examining and evaluating map-use skills, especially in natural environments. However, quantitative research studies of how people use maps for navigation in natural environments have not been adequate. The self-evaluation questionnaires in this study were invented according to the analysis of navigation task discussed above.

1.2. Contour interpretation

Since natural scenery is mainly composed of landforms, topographic features are important for self-location in natural environments. The most popular and efficient method of representing topographic features is contour lines. Although current technology enables us to make maps with easily understandable expression of landforms without relying on contour lines like as Red Relief Image Map (Chiba, Kaneta, & Suzuki, 2008), the comparison of contour interpretation revealed that contour maps were still better for interpreting local topographic character (Murakoshi, Koyama, & Uenishi, 2011). Contour expression could also provide individuals with greater confidence of self-location than do bird's-eye view maps (Kaplan, 1976). Therefore, the proper interpretation of contour lines is essential for navigation in natural environments and most of textbooks for land navigation devote pages to contour lines. Researches also clarified that contour lines or landforms expressed on the map are major feature to which map readers pay attention during navigation (e.g. Seiler, 1989; Whitaker & Cuqlock-Knopp, 1992) and reference to topographic features correlates with performance of map–terrain association tasks (Montello, Sullivan, & Pick, 1994). Thus, contour line interpretation is essential for navigating in natural environment.

Unlike other map symbols, contour lines do not have direct correspondence in the environment. This means that visualization of landforms might be necessary when using topographic maps for navigation. The difficulty of landform visualization from contour lines has been pointed out from a cognitive viewpoint (Matthews, 1992; Sholl & Egeth, 1982) and a practical viewpoint (Bratt, 2002; Kals & Soles, 2005). Although mental representation from contour lines has been studied in the framework of visual imaging (e.g. Eley, 1989, 1992), a study of topographic map reading clarified that the scores of contour tasks were primarily dependent on verbal-analytic ability rather than visuospatial ability (Sholl & Egeth, 1982) measured by paper-and-pencil spatial ability test. Although the contour interpretation is regarded as an image generation and image transformation process, the generation of 3D image of landforms from contour lines might involve more analytic processes than naively believed.

If we assume that the contour lines are analyzed rather than automatically visualized when image of landform was generated, a number of steps may be necessary. First, the smaller curvature radius of a contour curve should be detected and interpreted as a ridge or a valley. In addition, one should know which side of the contour line is higher to determine whether the curve represents a ridge or a valley. Second, because mountain shapes are characterized by ridge or valley lines that are typically distinct in the field, these lines on a map should be traced to correspond with ridge and valley lines in the environment. These lines can be traced by connecting parts of minimum curvature radii on adjacent contour lines. Lastly, for complete visualization of landforms, one must transform shapes of the contour lines as well as space between contour lines into slope inclination.

Given the above considerations, contour interpretation might be a multi-stage process: (1) High–low judgment; (2) Landform judgment; (3) Ridge–valley lines judgment and (4) Construction of detailed landform shapes. They might demand two kinds of cognitive skills, two-dimensional pattern recognition and the transformation of two-dimensional patterns of contour lines into 3D images of landform. A factor analysis on a geographical map interpreting task that demanded awareness to a salient steep slope in addition to simple contour tasks yielded two independent factors: *General contour reading* and the *Inclination of slope* (Murakoshi, 2008), consistent with above assumption.

1.3. Aim of the research

The aim of this study is to investigate the cognitive characteristics associated with mountaineers' navigational map use. In the current study, mountaineering referred to hiking or outings of various lengths of time in mountain ranges. Particularly, this research aims to:

(1) Investigate cognitive components of navigational map use in natural environments;
(2) Identify cognitive skills utilized in contour interpretation and
(3) Clarify how contour interpretation skills and navigational map use of mountaineers develop with experience.

Figure 1 illustrates construction of the current study. Contour interpretation skills were assessed by objective contour tasks and cognitive components of navigational map use were assessed by a subjective questionnaire. Map-use experience was assumed to be an independent variable to navigational map use and contour interpretation, which in term were assumed to be independent variables to wayfinding behavior. The results of this inquiry may contribute to clarifying cognitive characteristics of navigational map use in natural terrain, improving mountaineers' navigational map-use skills, and reducing mountain accidents due to poor navigation skills.

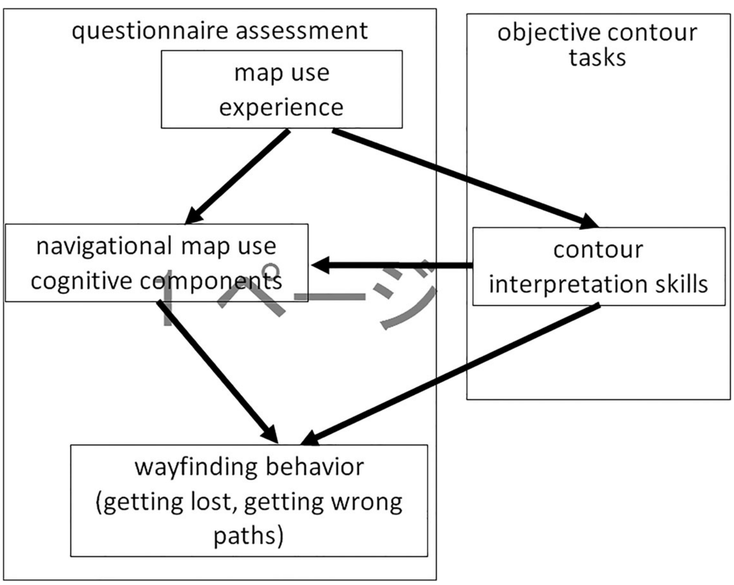

Figure 1. Construction of the current study. Navigational map use was assessed by objective contour tasks and cognitive components of navigational map use assessed by subjective questionnaire. Map-use experience is assumed to be an independent variable to navigational map use and contour interpretation skills, which are in turn independent variables to wayfinding behavior.

2. Method

2.1. Participants

One hundred and sixty mountaineers participated in the study. Five participants were excluded due to incomplete responses, resulting in a total of 155 participants (127 men, 26 women and 2 unspecified). The participants' mean age was 29.4 (SD = 12.0), mean mountaineering experience was 6.5 years (SD = 8.0), and mean map-use experience for mountaineering was 5.0 years (SD = 7.4), ranging from beginner with very little experience to expert with more than 30 years of experience. The participants were recruited from eight mountaineering training courses, six of which were organized by the National Center for Mountaineering Education in Japan and two of which were for local leaders or soon-to-be leaders. The courses aimed to refresh the participants' general mountaineering skills including a short indoor lecture and exercise of navigational map use followed by outdoor exercises. The majority of the participants were members of university mountaineering clubs, and the remaining participants were full-time workers who were considered to be serious mountaineers.

The questionnaires were also distributed to 239 mountaineers, whose experience ranged from less than 1 year (expressed as 0 years) to 36 years (mean = 7.3, SD = 8.5) and map-use experience for mountaineering ranged from 0 to 36 years (mean = 3.7, SD = 6.6). These participants were recruited from short mountain navigation training courses. Of these participants, 32 were excluded due to incomplete responses. Combining the two samples, a total of 362 questionnaires were included in the analysis (244 men, 101 women and 17 unspecified). The participants ranged in age from 18 to 72 years (mean = 37.0, SD = 14.5).

2.2. Materials

2.2.1. Questionnaire

A self-evaluative questionnaire of 18 items concerning map use during mountaineering trips was prepared. The items were obtained from field navigation textbooks and theoretical consideration of navigational map use, as discussed in subsection 1.1. The items included the basic understanding of map symbols, contour line interpretation, ability to determine one's position and to remain on a route, and so on. In addition to these skills, tendency toward carrying and referring both a map and compass were assessed, as it has been reported that quite a lot of casualties of mountain accidents due to getting lost did not carry a map and compass and that mountaineers often do not appropriately refer to a map and compass. Thus, they are regarded as essential components of map use in naturalistic situation. As reported below, the importance of each item for field navigation was assessed by an expert map reader. The experience of getting lost and the experience of taking the wrong path during mountaineering were also asked (see Table 1). A four-point rating scale that consisted of '4 yes', '3 rather yes', '2 rather no' and '1 no' was used for all of the items. The participants' gender, age, mountaineering experience and map-use experience for mountaineering were also assessed. Self-evaluation questionnaires have been used to measure navigation ability or strategies (e.g. Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002; Lawton, 1996; Liben, Myers, & Christensen, 2010) and have demonstrated a certain extent of validity. They can assess behavior

Table 1. Navigational behavior while mountaineering.

Items	No	Rather no	Rather yes	Yes
1 I carry a map(s) while mountaineering	24	26	49	263
2 I refer to a map(s) while mountaineering	37	75	128	122
3 I carry a compass while mountaineering	55	37	40	230
4 I refer to a compass while mountaineering	93	97	78	94
5 I can identify ridges and valleys from contour lines	40	51	109	162
6 I can visualize saddles as topographic features	74	29	92	167
7 I can distinguish between magnetic north and true north	47	33	83	199
8 I can maintain my travel direction by means of a base-plate compass	97	81	88	96
9 I can visualize features from map symbols	51	129	135	47
10 I can visualize inclination of slopes from contour lines	30	81	161	90
11 I can properly align a map	150	66	83	59
12 I read the characteristics of routes from maps before I hike	58	88	148	68
13 I can visualize characteristics of routes from the maps	70	110	142	40
14 I can decide my travel direction by aligning maps	143	76	88	51
15 I am conscious of the direction when I maintain planned routes	37	75	166	84
16 I am conscious of the characteristics of landforms around me when I maintain planned routes	40	95	137	90
17 I know what to do when I get lost	54	108	135	65
18 I usually know where I am while mountaineering	43	79	175	65
19 I have experience of taking the wrong path while mountaineering	48	34	78	202
20 I have experience of getting lost while mountaineering	77	61	70	154

and skills which are otherwise difficult to assess and also provide an opportunity to collect a large amount of data that are otherwise difficult to collect from the mountaineers.

2.2.2. Contour tasks

To measure contour interpretation skills, four contour tasks, described in Potash, Farrell, and Jeffrey (1978) and Sholl and Egeth (1982), were administered. These four tasks correspond to the contour interpretation process discussed above and regarded as valid to assess contour interpretation skills. The four contour reading tasks are as follows:

(1) High–low judgment (10 items): Participants judge which of 2 points that are displayed on maps is higher.
(2) Landform judgment (12 items): Participants judge whether given points are on a ridge or a valley. This task consists of two types of items, those with high–low judgment clues such as peaks and streams and those without such clues.
(3) Ridge–valley judgment (12 items): Participants judge whether given lines on maps are on a ridge, a valley, or neither (mixture of ridges and valleys).
(4) Line-of-sight (Defilade) task (16 items): Participants judge whether two points that are indicated on a map can be viewed from each other. This task consists of two types of items, those in which two points are separated by a ridge (invisible) or a valley (visible) and those in which two points are on a concave slope (visible) or a convex slope (invisible). The items might require generation of three-dimensional images or disposition of slopes. The items were selected from a previous study (Murakoshi, 2009) considering the time required and percentage of correct answers such that participants could not complete all items within the given time. Sample pieces

and scenery were chosen from maps of moderate hills in countryside and relatively steep mountain ranges, both of which were familiar to ordinary mountaineers. These items were produced with 1:25,000 topographic maps of Japan. They were scanned with a resolution of 300 dpi and 15 by 15 mm in size. All items of each task were printed on an A4 piece of paper and presented to the participants at approximately 200% size.

(5) The map–terrain association task (Tkacz, 1998): This task requires participants to associate photos of natural scenery with a topographic map of the area to identify the location of the points displayed on the photos. The task requires contour interpretation for self-location. In the current study, 2 locations were indicated on each of 2 photos (one was an aerial photo of height of 2000 m altitude and the other was a photo from a ground perspective of undulating hills about 500 m altitude). The maps were scanned from 1:25,000 topographic maps with 300 dpi resolution, presented in actual size, and aligned to photos (Levine, 1982). Samples of the maps are shown in Figure 2.

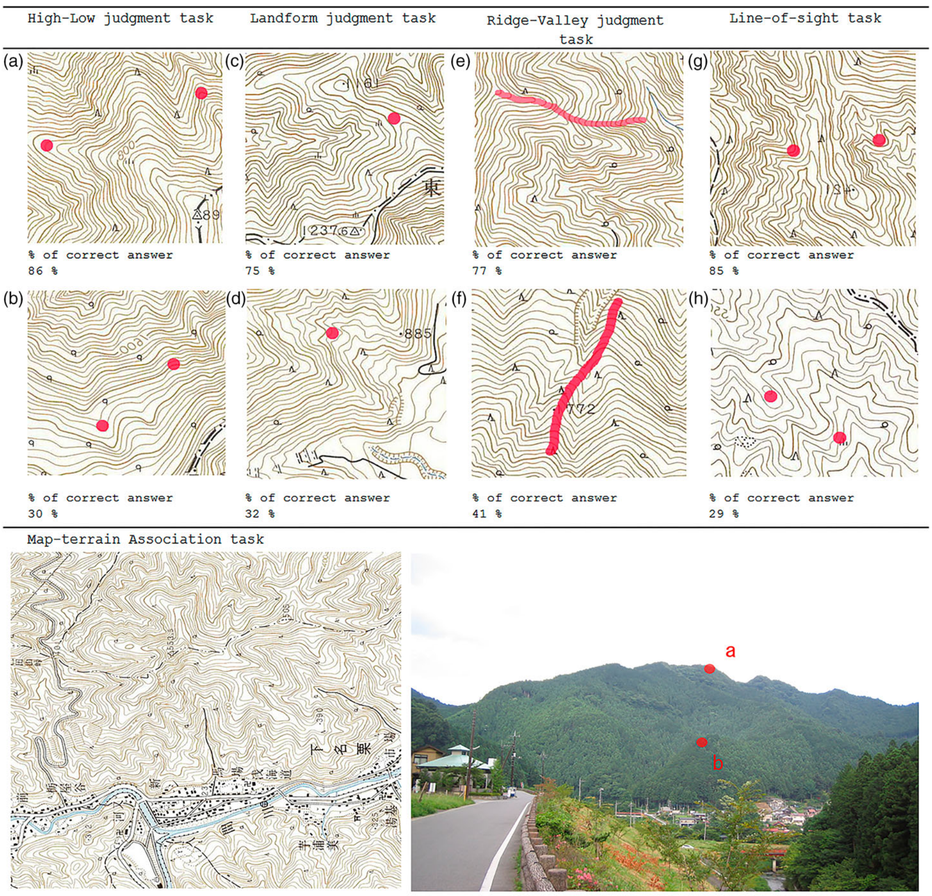

Figure 2. Example of contour tasks.

2.3. Procedures

Both the questionnaire and the contour tasks were administered at the completion of the courses as a self-evaluation of navigation and map-reading skills. The participants were provided with information concerning the purpose of the study and how the data would be handled and then asked to complete the questionnaires. All of the participants provided informed consent. Each contour task was administered in two and a half minutes, except the map–terrain association task, which was performed in five minutes. The tasks and the questionnaire were completed in a total of approximately 30 minutes, with only 5 minutes allotted for the questionnaire.

3. Results

The distribution of the response to items 11 and 14 indicated that the term 'alignment' was not properly understood, as shown in Table 1. Thus, these two items were excluded from further analysis. Nine experts of outdoor navigation rated the appropriateness of the items on a five-point scale. The mean rating of two items, '7 I can distinguish between magnetic north and true north' and '8 I can maintain travel direction by means of a base-plate compass', were lower than or nearly equal to 3.5 and, thus, were excluded from the analysis. I-T analysis indicated no other irrelevancies; therefore, the remaining 14 items were included in further analysis. The distribution of the responses is shown in Table 1.

3.1. Factor analysis of the questionnaire

The common factor analysis was conducted on the 14 items. A three-factor solution was regarded as the most relevant. The proportion of variance explained by three factors was 64.1%. The factor pattern matrix after Promax rotation is provided in Table 2.

Table 2. Pattern matrix of factor analysis of the questionnaire (Promax rotation after most likelihood method).

	F1	F2	F3	Communality
15 I am conscious of the direction when I follow planned routes	0.932	0.052	−0.180	0.701
16 I am conscious of topographic features around me when I maintain planned routes	0.764	0.021	0.127	0.769
12 I read characteristic of routes from maps before I hike	0.651	0.210	−0.012	0.625
17 I know what to do when I get lost	0.623	−0.086	0.197	0.532
18 I usually know where I am while mountaineering	0.623	0.070	0.176	0.658
13 I can visualize characteristics of routes from the maps	0.604	−0.064	0.350	0.734
1 I carry a map(s) while mountaineering	−0.039	0.849	−0.035	0.648
2 I refer to a map(s) while mountaineering	0.213	0.728	−0.118	0.640
3 I carry a compass while mountaineering	−0.131	0.655	0.271	0.576
4 I refer to a compass while mountaineering	0.222	0.465	0.160	0.565
5 I can identify ridges and valleys from contour lines	−0.078	0.220	0.738	0.689
6 I can visualize saddles as topographic features	−0.022	0.071	0.714	0.551
10 I can visualize inclination of slopes from contour lines	0.253	−0.095	0.639	0.620
9 I can visualize features from map symbols	0.364	−0.094	0.570	0.669
Correlation between factors				
F2	0.627			
F3	0.753	0.613		

None of the items had factor loadings that were higher than 0.4 on two or more factors. Thus, the items with factor loadings higher than 0.4 were used for interpretation and labeling of factors. The items with a higher loading onto the first factor were as follows: '15 I am conscious of the direction when I follow planned routes', '16 I am conscious of topographic features around me when I maintain planned routes', '12 I read characteristic of routes from the maps before I start', '17 I know what to do when I get lost', '18 I usually know where I am while mountaineering and '13 I can visualize the characteristics of routes from the maps'. These items concern navigational problem-solving, as described in the introduction section. Thus, the factor was named as *Solution of navigational tasks*. The items with a higher factor loading than 0.4 onto the second factor were as follows: '1 I carry a map(s) while mountaineering', '2 I refer to a map(s) while mountaineering', '3 I carry a compass while mountaineering' and '4 I refer to a compass while mountaineering'. These items relate to the tendency toward map and compass use. Thus, the factor was named as *Carrying and reference to map and compass*. The items with a higher factor loading than 0.4 onto the third factor were as follows: '5 I can identify ridges and valleys from contour lines', '6 I can visualize saddles as topographic features', '10 I can visualize inclination of slopes from contour lines and '9 I can visualize features from map symbols'. These items relate to the understanding of map symbols, including contour line interpretation. Thus, this factor was named as *Symbol understanding*.

The items '20 I have experience of getting lost while mountaineering' and '19 I have experience of taking wrong paths while mountaineering' displayed a high correlation ($r = 0.765$, $p < .001$). Thus, the sum of these two items was used as the index of *Experience of getting lost*.

A confirmatory factor analysis was conducted with the 14 items based on the above results. The three-factor model moderately fit the data, χ^2=430.3, Comparative Fit Index (CFI) = 0.900, Root Mean Square Error of Approximation (RMSEA) = 0.115 and Akaike's Information Criterion (AIC) = 520.3. The two-factor model, which combined *Solution of navigational tasks* and *Symbol understanding*, displayed less fit, (χ^2=503.6, CFI = 0.880, RMSEA = 0.125 and AIC = 589.6). The model with three factors was regarded as more relevant. The factor scale scores were obtained by summing the item scores that had factor loadings of higher than 0.4 on each factor. The alpha coefficients of the factor scale scores were as follows: 0.842 *(Carrying and reference to maps and compass*), 0.855 (*Symbol understanding*) and 0.918 (*Solution of navigational tasks*). The overall alpha coefficient for all 14 items was also very high (0.939). The means of the factor scale scores were used as indices of the acquisition of the cognitive components of navigational map use and, hereafter, are called the cognitive component scores. The total map-use score was calculated by summing all three cognitive component scores.

3.2. Map-use experience and the cognitive components of navigational map use

The partial correlation coefficient between the total map-use score and map-use experience adjusted for mountaineering experience was $r = 0.348$, $p < .001$ while the partial correlation coefficient between the total map-use score and mountain experience adjusted for map-use experience was $r = -0.147$, ns. Thus, map-use experience was used as an index of experience (Figure 1).

The participants were divided into four groups according to map-use experience: less than 1 year (Group 1), 1–2 years (Group 2), 2–4 years (Group 3) and 4 years or more (Group 4). A three-way ANOVA was conducted on cognitive component scores as the within-subjects and map-use experience and gender as between-subjects variables. The main effects of cognitive components and experience and their interaction were significant (main effect of experience group, $F(3,\ 310) = 59.113$, $p < .001$, $\eta_p^2 = 0.364$; main effect of cognitive components, $F(2,\ 620) = 40.106$, $p < .001$, $\eta_p^2 = 0.115$; interaction between experience and cognitive components, $F(6,\ 620) = 2.518$, $p < .05$, $\eta_p^2 = 0.024$). The main effect of gender was marginal but not significant ($F(1,\ 310) = 3.809$, $p = .052$). Significant simple main effects were obtained in all experience groups and all cognitive components. The results of ANOVA and post hoc paired comparisons are shown in Table 3.

3.3. Contour task performance

The score for each contour task was calculated by adding one point for each correct answer. I-T analysis clarified that several items were not discriminative; thus, these items were eliminated from further analysis. Eight items for High–low judgment, 10 items for Landform judgment, 10 items for Ridge–valley judgment and 14 items for Line-of-sight judgment were used for further analysis.

In the Map–terrain association task, answers with error within 3 millimeters on the map (approximately 75 meters in reality) were scored as 2 points and answers with error more than 3 millimeters but on the identical landform were scored as one point. Therefore, the maximum score was eight.

A confirmatory factor analysis was performed for the contour tasks. The one-factor model and the two-factor model indicated similar fit (one-factor model: $\chi^2 = 3.80$, CFI = 1.00, RMSEA = 0.00 and AIC = 33.797; two-factor model: $\chi^2 = 3.40$, CFI = 1.00, RMSEA = 0.00 and AIC = 35.397).

3.3.1. Map-use experience and the contour task scores

A two-way ANOVA with experience and gender as between-subjects variables was conducted on the task scores. The main effect of gender was only observed for the Line-of-sight task ($F(1,\ 143) = 7.331$, $p < .01$, $\eta_p^2 = 0.049$). The main effect of experience was found for all tasks: Landform judgment ($F(3,\ 143) = 3.140$, $p < .05$, $\eta_p^2 = 0.062$), Ridge–valley judgment ($F(3,\ 143) = 5.145$, $p < .01$, $\eta_p^2 = 0.097$), Line-of-sight ($F(3,\ 143) = 3.998$, $p < .01$, $\eta_p^2 = 0.077$) and Map–terrain association ($F(3,\ 143) = 3.113$, $p < .05$, $\eta_p^2 = 0.061$). Although no interaction was observed, a further examination revealed that the mean scores for females were dependent on their experience. Because of the small number of female participants, a one-way ANOVA of experience on task scores was conducted for males (Table 4). The main effect of experience was significant only for the Ridge–valley judgment ($F(3,\ 122) = 5.880$, $p = .001$, $\eta_p^2 = 0.126$).

3.3.2. Characteristics of contour lines that affect performance on the contour tasks

The percentage of correct answers on each contour task item was calculated, excluding the number of unanswered items. The percentages ranged from 34% to 89% (mean, 64%) for High–low judgment, 33% to 83% (mean, 59%) for Landform judgment, 41%

Table 3. Mean aspect scores of navigation behavior by map reading experience.

		Map reading experience (years)					
		<1	<2	<4	4<=	Simple main effect of map reading experience	Multiple comparison
Carrying and reference to maps and compasses (C)	Mean	2.379	3.293	3.420	3.527	$F(3, 310) = 53.27$ ***	1 < 2,3,4
	SD	0.869	0.694	0.617	0.494		
Symbol understanding (B)	Mean	2.196	2.849	3.227	3.524	$F(3, 310) = 73.38$ ***	1 < 2<3,4
	SD	0.740	0.727	0.544	0.490		
Solution of navigational tasks (N)	Mean	2.096	2.671	2.902	3.291	$F(3, 310) = 60.54$ ***	1 < 2,3 < 4
	SD	0.724	0.598	0.536	0.553		
Simple main effect of aspect of navigation behavior		$F(2, 620) = 11.30$ ***	$F(2, 620) = 36.85$ ***	$F(2, 620) = 14.31$ ***	$F(2, 620) = 7.16$ **		
Multiple comparison		B,N < C	N < B<C	N < B,C	N < B,C		

**$p < .01$.
***$p < .001$.

Table 4. Contour task scores by experience of map reading (male only).

		<1	<2	<4	<=4	Main effect of experience	Multiple comparison
High–low judgment	Mean	4.385	4.971	5.160	5.057	$F(3, 122) = 0.831$, ns	
	SD	1.261	1.272	1.405	1.748		
Landform judgment	Mean	5.154	5.771	5.800	5.887	$F(3, 122) = 0.540$, ns	
	SD	1.144	1.646	2.121	2.016		
Ridge–valley judgment	Mean	4.000	5.800	6.240	6.491	$F(3, 122) = 5.880$, $p = .001$	0 < 1,2/3,4
	SD	1.732	1.762	2.296	1.957		
Line-of-sight	Mean	6.923	7.629	6.600	7.811	$F(3, 122) = 1.458$, ns	
	SD	2.326	2.658	2.327	2.746		
Map–terrain association	Mean	2.769	2.229	1.920	2.698	$F(3, 122) = 2.120$, ns	
	SD	1.363	1.497	1.256	1.501		

to 77% (mean, 62%) for Ridge–valley judgment and 29% to 87% (mean, 55%) for the Line-of-sight task. For the Landform judgment task, the mean percentage of correct answers with clues and without clues which enabled easier high–low judgment were nearly identical (without clues: 0.58 and with clues: 0.60). For the Line-of-sight task, the percentage of correct answers on items in which two points were separated by ridge or valley was 61% and that on items in which 2 points were on convex or concave slopes was 48%.

To identify contour characteristics that influence difficulty of judgment, the percentage of correct answers for each item was compared between participant groups with upper and lower total scores of contour task. Significant differences were found in five of the six Landform judgment items and all six Ridge–valley judgment items. There were no such clear tendencies in the Line-of-sight and High–low judgment tasks.

For the Map–terrain association tasks, the percentages of correct answers were high when the points were on distinguishable topographic features, whereas they were between 1% and 10% when the points were on small detailed features. Approximately 20–30% of the answers were on the identical features but not on the correct points; thus, they were awarded one point.

3.3.3. Relationship between the contour task and cognitive components of navigational map use

Structure equation modeling was employed to test the multiple indicator model in which *Contour interpretation skills* influenced *Navigational map use*, and *Navigational map use* influenced *Experience of getting lost*. Here, *Navigational map use* was the second order factor from the three cognitive components of navigational map use (Figure 3). The result indicated a moderately good fit, χ^2=549.0, CFI = 0.911, RMSEA = 0.074 and AIC = 685.0. The coefficient of *Contour interpretation skills* and *Navigational map use* was 0.68. The coefficient between *Navigational map use* and *Experience of getting lost* was 0.36.

Table 5 indicates the correlations between the contour task scores and the three cognitive components scores and overall scores. All correlations of the cognitive components scores and contour tasks were significant except the correlation between *Solution of navigational tasks* and the Map–terrain association task. Ridge–valley judgment had the highest correlation with all cognitive components score among all contour tasks, and *Symbol understanding* had the highest correlation with all contour tasks among all

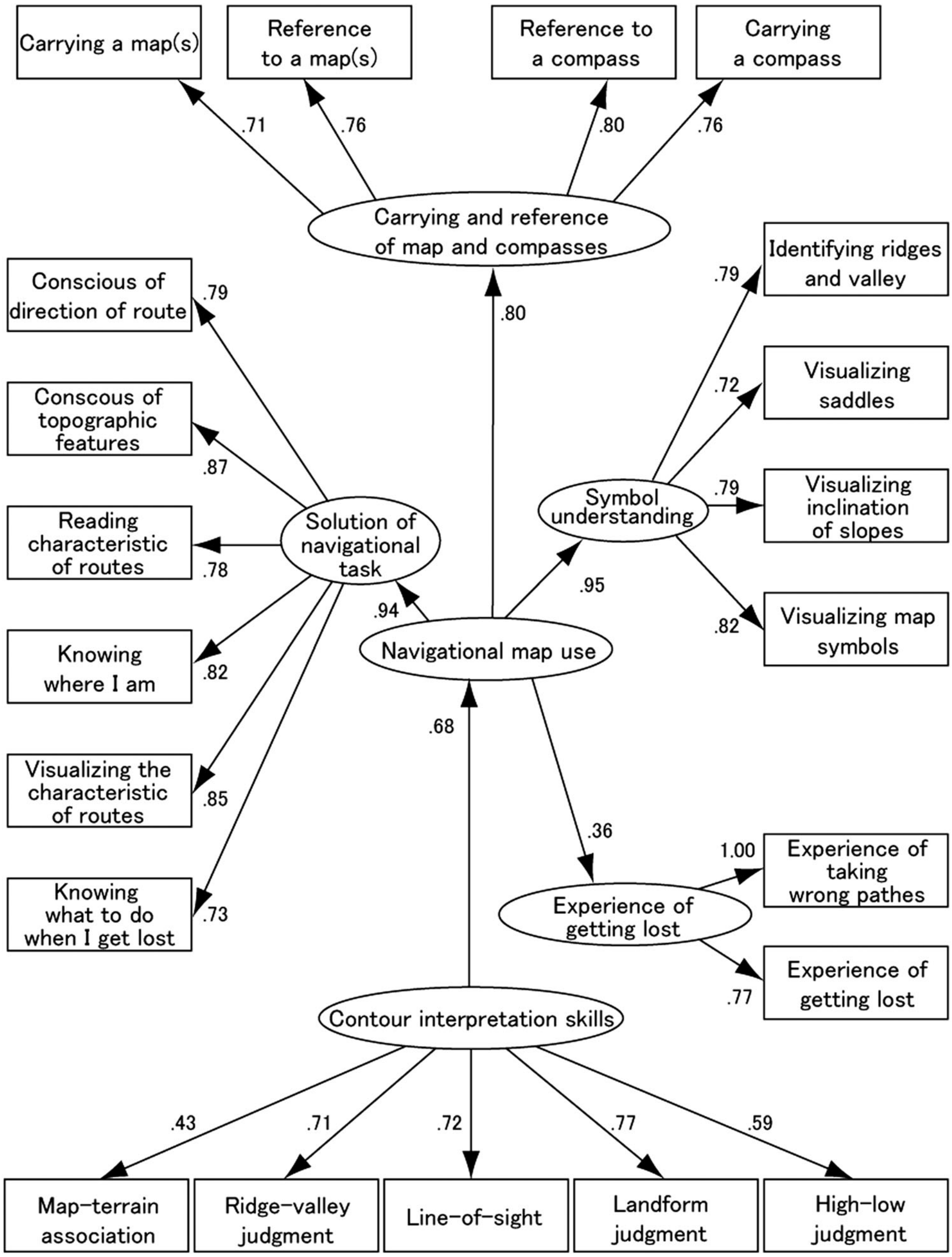

Figure 3. Multiple indicators model of the relationships among map reading, navigational behavior and experience of getting lost.

cognitive components. A comparison of demographic variables between the groups with the lower/higher scores of navigational map use among the participants who had the lower total contour interpretation task scores revealed a significant difference only in map-use experience ($t(65.351) = 2.605$, $p < .05$).

Table 5. Correlation between contour task scores and cognitive component scores.

	Carrying and reference to maps and compasses	Symbol understanding	Solution of navigational tasks	Total scores
High–low judgment	0.209	0.219	0.186	0.238
	0.009	0.006	0.020	0.003
Landform judgment	0.178	0.399	0.249	0.324
	0.027	0.000	0.002	0.000
Ridge–valley judgment	0.297	0.514	0.408	0.483
	0.000	0.000	0.000	0.000
Line-of-sight judgment	0.169	0.384	0.309	0.346
	0.035	0.000	0.000	0.000
Map–terrain association	0.174	0.210	0.130	0.195
	0.031	0.009	ns	0.015
Total scores	0.273	0.498	0.373	0.451
	0.001	0.000	0.000	0.000

Note: The upper and the lower rows indicate correlation and significance, respectively.

4. Discussion

4.1. Cognitive skills of contour interpretation

The assumption of the current study was that cognitive skills for contour interpretation were multifaceted. The different improvement patterns among contour task scores with map-use experience and the fact that gender difference was observed only in Line-of-sight task endorsed that contour interpretation consists of multiple cognitive skills, although there was no positive evidence from the confirmatory factor analysis comparing the one-factor model with the two-factor model of contour tasks.

In general, the High–low judgment task and the Map–terrain association task had a lower coefficient to overall *Contour interpretation skills* than the other three contour tasks. The lower factor loading to High–low judgment task was consistent with Tkacz (1998) and Sholl and Egeth (1982), in which elevation estimation and contour comprehension were regarded as different factors. The other three tasks require identifying characteristics of contour curvature in order to interpret the curvature to landform, whereas the High–low judgment can be achieved without such identification. On the other hand, the lower coefficient of the Map–terrain association task to overall contour task was contrary to Tkacz (1998). This might be attributed to differences in the task materials. In Tkacz's tasks, answer choices were provided and answer clues had easily distinguishable topographic features. By contrast, the tasks contained relatively complicated landforms judgment, few easily identifiable artificial objects, and no answer choices provided in the current study. Thus, the tasks might demand more complicated skills like logical reasoning (Pick et al., 1995; Tkacz, 1998) or comparison and confirmation strategies (Murakoshi, 1988; Pick et al., 1995). Requirement of such skills in Map–terrain association may have reduced commonality with other contour judgment task.

Stronger support for multiple cognitive skills of contour interpretation was obtained from gender differences in the Line-of-sight task and experience differences only in the Ridge–valley judgment task. The most robust and largest effect size between males and females in spatial abilities was found in mental rotation, or tests that require the transformation of a two-dimensional problem into a three-dimensional solution (Voyer, Voyer, & Bryden, 1995) and the gender difference is largely explained by capacity of working memory (Coluccia & Louse, 2004; Kaufman, 2007). Investigation of gender differences in map reading also found that working memory capacity contributed to gender differences of map reading (Allen, 2000). Differences that favored men were also reported for map learning tasks that required the use of visuospatial working memory (Coluccia, Bosco, & Brandimonte, 2007). The result that only the Line-of-sight task showed gender difference implied that the task is somewhat unique among contour line tasks by demanding visuospatial working memory.

Improvement with experience of map use was only observed in the Ridge–valley judgment task. To identify ridge or valley as lines, it is necessary to connect the tops of the contour curvatures of adjacent contour lines. The result indicates two things: one is that the task requires cognitive skill(s) that differ(s) from those of interpreting characteristics of contour curvature to landform, and the other is that only this skill was gradually acquired by map-use experience.

The results that the contour tasks including multiple cognitive skills yielded only one factor is inconsistent with prior assumption. This might be attributed to the materials that were used for the tasks. The materials were created from relatively complicated real topographical maps. Therefore, they might require awareness and knowledge of contour curvatures and general skills of pattern recognition from rather complicated contour lines regardless of the specific demand of the tasks such that a major portion of variance was explained by one factor.

4.2. Cognitive components of navigational map use

Main finding of this study is that *Solution of navigational tasks* and *Symbol understanding* are different cognitive components of map use. This was concluded from the result that confirmatory factor analysis revealed that a model in which the two factors were separate showed a better fit. In addition, the contour tasks mostly correlated higher with *Symbol understanding* than with *Solution of navigational tasks*, and comparison among experience groups revealed that the two cognitive components had different improvement patterns with experience. Basic symbol understanding does not directly lead to the ability to use the map for navigation including route keeping and self-location.

Map–terrain association tasks displayed a low correlation with *Solution of navigational tasks*, contradictory to the result of Lobben (2007), who reported that self-location tasks were a strong indicator of navigation performance as gauged by time. One possible reason for the contradictory results is differences in the task environments. The self-location in natural environments with a limited number of distinct features might demand broader skills compared to artificial environments in which Lobben's study was conducted. Another potential reason is that *Solution of navigational tasks* was measured by a self-evaluation questionnaire in the current study. In addition, the Map–terrain association task at the drop-off mode used in this study might demand different sub-skills from self-location tasks of actual navigation, in which features that were observed during the travel to the current position are also available for determination of location.

Although *Carrying and reference to maps and compasses* yielded one factor, the number of negative responses to the reference to a compass item was nearly double that of the reference to a map items (Table 1). This means that maps and compasses may not be used equivalently in outdoor navigation, although most practical navigation textbooks treat maps and compasses equally. Even in a simple artificial environment, the human error of indicating a facing direction on a map was 42.52 degrees, but better when maps were aligned in natural setting (Liben et al., 2010). A compass is virtually the only equipment that enables navigators to align maps accurately in natural terrain but the mountaineers might not be aware of importance of compasses for aligning maps in order to head right direction, thus to keep on a route.

The standardized coefficient from *contour interpretation skills* to the secondary factor *Navigational map use* was fairly high (0.68) compared to the coefficients in previous studies that reported a relationship between self-evaluation questionnaires and results from an objective task of spatial ability. The correlations between self-evaluated sense of direction and pointing accuracy were 0.61 (Bryant, 1982) and 0.20–0.30 (Takeuchi, 1992), respectively. Furthermore, the correlations between self-efficacy of indoor navigation and anxiety and pointing task (Lawton, 1996) were 0.41 and 0.31, respectively. According to these results and considering that contour interpretation is the most essential skills in mountain navigation, it seems that self-evaluation of navigation satisfactorily reflects navigation skills of mountaineers, although there was tendency of over-judgment of self-assessment according to experience. From the above discussion, the scores of *Carrying and reference to map and compass*, *Symbol understanding* and *Solution of navigational tasks* are regarded as valid and reliable indices of navigational map use in natural environments.

4.3. Mountaineers' acquisition of navigational map use and contour interpretation skills by experience

The cognitive component scores were mostly lower in Experience Group 1; however, *Carrying and reference to maps and compass* was relatively higher and increased only between Experience Group 1 and Experience Group 2. By contrast, scores for *Symbol understanding* and *Solution of navigational tasks* increased continuously after two years of experience, but the scores for *Solution of navigational tasks* remained lower in Experience Group 4 compared to the other two cognitive components. The improvement pattern of the scores indicated that cognitive components of navigational map use are acquired through the following stages: (1) increasing the tendency of carrying and referring maps and compasses, (2) understanding map symbols and contour lines and (3) utilizing map symbols and contour lines for navigational problem-solving. *Solution of navigational tasks* did not fully improve even among mountaineers with more than four years of map-use experience.

Contrary to the increasing trend of the *Symbol understanding* score with experience, an improvement in contour task performance among males was only observed for the Ridge–valley judgment task. Because the average percentage of the correct answers ranged from 50% to 60%, the results cannot be attributed to the ceiling effect. The skills of contour interpretation are only partially mastered even after four years of map-use experience. This might be attributed to the characteristics of Japanese mountain ranges; ridge and valley lines are typically distinct and major mountaineering routes follow these lines because Japan is situated in an orogenic zone and upheaval and erosion movements are highly active. In such an environment, the judgment of ridge–valley lines is the most important and sufficient for navigation for ordinary mountaineering. The performance improvement patterns of the contour tasks might be the result of adaptation to such environment.

Although the correlations between self-evaluation of navigational map use and contour tasks performance were not low, several factors may have reduced the correlations. One of such factors is mountaineers' overestimation of their skills according to their experience. Significant differences of map-use experience were found between the high/low self-evaluation groups among participants of lower contour task scores. Another factor is discrepancy of skills that *Navigational map use* and basic contour tasks measure. Navigational tasks in natural environments require not only an understanding of symbols and contour lines but also problem-solving skills that include logical reasoning and confirmation processes for determining one's position in environments where features are ambiguous (Pick et al., 1995). The acquisition of skills might not be measurable by basic contour tasks. The development of tasks that appropriately measure these skills for navigational problem-solving using maps is an important future research challenge from both practical and theoretical points of view.

4.4. Practical issues of mountaineers' navigational map use

According to the results, several deficits in mountaineers' navigation skills were identified. First, the basic skills of contour interpretation seem to be insufficiently developed. From the Ridge–valley judgment task, the mountaineers' most common difficulty was tracing the ridge or valley lines, especially when the lines were not distinct. They also had difficulties visualizing detailed landform shapes through the detection of transitions of slope inclinations. A comparison between participant groups with the higher and the lower contour task scores revealed that their differences existed in items that contained less complicated topographical features rather than more complicated features. The difference between good and poor map readers may stem from lack of basic contour reading skills. During map reading practice, basic principle of contour lines and their interpretation should be stressed and repeatedly practiced.

Second, a positive correlation between *Navigational map use* and *Experience of getting lost* was observed. Although the *Experience of getting lost* items were asked based on all past mountaineering experiences, it is unlikely that the positive correlation was mediated by map-use experience, since the correlation between map-use experience and the two items of *Experience of getting lost* was significant but not high ($r =$ 0.166 for '19 taking the wrong path' and 0.122 for '20 getting lost'). Mountaineers are inclined to evaluate their navigational map use as better with increased map-use experience, even though their objective skills did not improve. In challenging activities such as mountaineering, an individual may attempt more difficult routes if he or she believes that he or she had improved skills in order to fulfill a sense of sensation and achievement, as predicted by the risk homeostasis hypothesis (Wilde, 2001). This might result in more experience of getting lost when they evaluated their skills higher than actual states, thus positive correlation between *Experience of getting lost* and *Navigational map-use* skills.

Third, *Solution of navigational tasks* scores increased with experience, but remained relatively low compared to other cognitive components of navigational map use. The skills of solving navigational tasks do not seem to be sufficiently acquired, even with relatively longer map-use experience, probably because of its complicated nature discussed previously. In an educational setting, stress should be on the nature of the navigational tasks and acquisition of skills for the tasks.

5. Conclusion

The following three cognitive components of navigational map use were identified by factor analysis of questionnaires: *Carrying and reference to map and compass*; *Symbol understanding*; and *Solution of navigational tasks*. One of the important findings of this study is that symbol understanding and map reading for navigation problem-solving are independent components to some extent. In addition to the basic skills of interpreting map symbols, cognitive skills for solving navigation problems might be essential for successful navigation in natural environments. The lack of such skills might be one reason why adults with cognitive ability of map understanding are prone to navigational errors in natural environments.

The current study also implies that multiple cognitive skills are utilized in contour interpretation. These skills include comprehension of two-dimensional contour patterns, tracing ridge and valley lines that are not indicated on maps, and generation and manipulation of three-dimensional representations. Only a limited number of research studies have addressed the complexity of navigational behavior in natural environment (e.g. Montello et al., 1994; Pick et al., 1995) to date. Additional exploratory studies are needed to understand the processes and skills of symbol use in a complicated and ambiguous environment. A longitudinal study with objective measurements is needed to confirm the results of the current study. Considering the complex nature of navigational tasks, how one acquires the skills of problem-solving for navigation is an interesting topic of research. On the other hand, field navigation demands limited skills according to the characteristics of the environment and tasks. A survey that compares navigational map use in different environments may also clarify how necessary skills relate with characteristics of the environment.

The necessity of the basic and systematic learning of contour interpretation can be addressed from a practical viewpoint. The training of map reading should stress task demand of navigational map reading in order to facilitate problem-solving skills of navigation as well as basic contour interpretation skills, and thus, promote efficient map reading.

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