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Research Article

Eye-catching or breath-catching: Role and landscape attributes of pauses differs among hikers' profile when rambling in a French mountainous area

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ABSTRACT

The trajectory of a hiker can be decomposed in walking sections and pauses. The attributes and possible roles of pauses in a hike has been under-looked in studies of human mobility in nature. In mountains, pauses can have several functionalities, depending on whether they occur by choice or are imposed by the lack of people fitness walking in arduous terrain. We studied the trajectories of mountain hikers from a pause point of view, based on GPS-trackers and questionnaires. We proposed a typology of pauses at the within-trajectory level, defining ”Longest”, “Eye-catching” and “Breath-catching” pauses. We then contrasted their characteristics (duration, number, and landscape variables), and their occurrence, number and duration in hikes depending on hiker groups attributes (size, age and gender structure). Longest pauses occurred most often close to summits, eyes-catching pauses close to passes and breathcatching pauses in steep terrain. Group size, and to a lesser extent, age structure, determined the number and total duration of pauses. Cumulated duration in breath-catching pauses made up one fourth of the pause duration on average. A better assessment of the functionality of pauses should therefore be pursued, especially in the context of hike planning, time budget, group dynamics and satisfaction.

Management implications

Hikers' pauses have implications for outdoor recreation managers with message disposal, environmental protection and planification:

- The pauses could have an impact on vegetation and on wildlife, and this impact could change wether time spent in pause is important.
- Formal messages and informative panels could be disposed on places where pauses occur more often.
- Spatio-temporal insights on pauses will help hikers optimizing the excursion planification.

1. Introduction

1.1. Recreation ecology: challenges and new methodological developments

Mountain areas provide great opportunities for the development of nature-based recreation (Martín-López et al., 2019), which has been increasing and diversifying in the last two decades (Hautbois, Mao, & Langenbach, 2009; Hunziker & Zeidenitz, 2006; Melo, Van Rheenen, & Gammon, 2020). Walking in general appears to contribute to human well-being (Barragan-Jason, Loreau, Mazancourt, Singer, & Parmesan, 2023; Hanna et al., 2019; Ritpanitchajchaval, Ashton, & Apollo, 2023), and mountains are considered as natural places to escape the hassle of crowded urbanized areas, as a playground for leisure sports, and are sought after for their scenic beauty (Beza, 2010; Nepal & Chipeniuk, 2005; Scarpa, Chilton, Hutchinson, & Buongiorno, 2000; Schirpke, Tasser, & Tappeiner, 2013b). Meanwhile, they are also important assets in terms of biodiversity (Korner & Spehn, 2019) and comprise a large number of protected areas worldwide with a variety of protection status (Bender, Roth, & Job, 2017; Héritier & Laslaz, 2008). Combining conservation and recreation encompassing different types of outdoor activities can however be conflicting (Martín-López et al., 2019; Reis & Higham, 2009), as impacts of recreationists are manifold, through e.g. trampling, disturbance of wildlife, or pollution (Hammitt, Cole, & Monz,

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2015). Recreation ecology, a field of study that rose in the late 20th century (Hammitt et al., 2015; Liddle, 1997; Manning, 2010) aims at better evaluating the potential impact of recreationists on their natural environment (Depraz, 2008; Kerlinger et al., 2013; McCahon, Brinkman, & Klimstra, 2023; Monz & D'Antonio, 2009) and managing nature-based tourism (Beeco & Hallo, 2014), an endeavor that calls for a better understanding of recreationists motivation, knowledge and behavior (Gruas, Perrin-Malterre, & Loison, 2020; Hanna et al., 2019).

Studies of hikers in the realms of sport, tourism, recreation ecology, and landscape management have been performed based on multiple techniques such as direct observations, questionnaires, interviews, and, in the last decades, using GPS tracking or automatic counting devices (Beeco & Brown, 2013; Dodge, Weibel, & Lautenschütz, 2008; Job, Majewski, Engelbauer, Bittlingmaier, & Woltering, 2021; McArdle, Demšar, van der Spek, & McLoone, 2014; Shoval & Isaacson, 2007; Spangenberg, 2014) as well as data obtained through social medias (Wilkins, Wood, & Smith, 2021). Combined with the development of computer capacities, GIS and statistical tools, vast amount of data provided by such automatically recording devices can now be analyzed, helping to identify different characteristics of individual trajectories in a landscape (Pickering, Rossi, Hernando, & Barros, 2018; Spangenberg, 2014). Hence, it is now becoming possible to collate different sources of data, which is as a powerful way to get a more comprehensive overview of outdoor activities from multiple point of views (Clayton et al., 2017; Hanna et al., 2019) focusing on the people (e.g. who they are, why they come, their knowledge, opinions and attitudes towards nature), on their interaction with their environment (e.g. where they go, how they behave, how they feel) and on their impact (trampling, disturbing, polluting, Marion (2023)). These three points of views should be tackled together for enabling stakeholders to implement management actions leading to a better interaction between human activities and environmental conservation (Hanna et al., 2019; Job et al., 2021).

1.2. Conceptual background

GPS data from hiking experiences is a type of mobility data that can be conceptualized through the time-geography theory lense (Hägerstrand, 1970a) with the three constraints applied to every hiking trip (capacity constraint, coupling constraint, authority constraint), and a recent call for new forms of data in order to "nuance individual experience" has been made (Dodge & Nelson, 2023). Time-geography has also been a way to conceptualize places in geography as "Pockets of Local Order" (Hägerstrand, 1985); Lenntorp (2004); Ellegård and Vilhelmson (2004)] with spatial, temporal and social key dimensions. Hiking can be approached as a way to link places where activities can be shared, through an itinerary, with constraints. The trips of hikers in protected areas are commonly assessed through different components linked to their mobility (hiking speed along their hike (Campbell, Dennison, Butler, & Page, 2019; Schamel & Job, 2017b), time-budget (Chardonnel & Van der Knaap, 2002; Fennell, 1996; Orellana, Bregt, Ligtenberg, & Wachowicz, 2012), and space use (use of paths or walking off-path (Peterson, Brownlee, & Marion, 2018; Winter, 2006; Wolf, Hagenloh, & Croft, 2012)). These different components should vary depending on people's goals, motivation, age, fitness, and socio-demographic characteristics (Bolduc, 1973; Schamel & Job, 2017a; Taczanowska, 2009). For instance, people motivated by training outdoor should move faster, keep on track, allocate a limited amount of time to pauses (capacity constraint), while a family with kids or a large group may move at a slower pace (capacity and coupling constraint), and choose sought-after scenic areas for longer lunch and snack pauses (Campbell et al., 2019; Orellana Vintimilla, 2012). In all cases however, the topography of mountains imposes constraints on time allocation (Chhetri, 2015), born upon individuals differently depending on their fitness (capacity constraint). Some of a hike's characteristics, and most specifically the amount of stops along the way, may therefore not result from actual choices, but from the physical need to rest (capacity constraint) or wait for lesser-trained persons in a group (coupling constraint). While the trajectory of a moving entity (e.g. a hiker) is made of spatial coordinates and timestamps (Zheng & Zhou, 2011) often summarized through descriptive statistics such as speed, distance, or sinuosity, it can also be viewed as a succession of moves and pauses (Alvares et al., 2007; Buard, 2013; Dodge et al., 2008; Spaccapietra et al., 2008; Tietbohl, Bogorny, Kuijpers, & Alvares, 2008). The latter have been less under the focus of studies than moves per se (Campbell et al., 2019), apart from the main stops (usually when reaching the target of the hike), though they are an intrinsic component of an itinerary and of the time-budget of hikers. We posited here that studying the distribution, duration and landscape attributes of all pauses, not only the main ones, should give an original insight on how people cope with the trade-off between the physical difficulty inherent to walking in the mountains (Chhetri, 2015) and expected rewards due to reaching their initial target. It is directly rooted in Hägerstrand framework (1970) whereby age, gender and limited human movement with high terrain constraints could inform on capacity constraints, while group composition corresponds to the coupling constraints (Schamel & Job, 2017a). The authority constraint would be policies from environmental managers, to restrict areas where one can hike or rest. From a manager point of view, it should also help identifying not only the obvious attracting places that people planned to get to ahead of their hike (e.g. scenic viewpoints, mountain huts, summits), but also where resting places occur along a hike's trajectory (Juutinen et al., 2011; Taczanowska, Muhar, & Brandenburg, 2008). If the location of pauses resulting from people's need to catch their breath are predictable, managers could both identify them in the landscape, advertise them as landmarks or intermediate goals, and possibly develop them with short information posts or resting facilities (Juutinen et al., 2011; Mäntymaa, Tyrväinen, Juutinen, & Kurttila, 2021).

1.3. Objectives

Within this framework, our endeavor here was to combine an analysis of mountain hikers' trajectories obtained by GPS-tracking devices to questionnaires in order to (1) identify the spatio-temporal characteristics of pauses within each mountain hiker trajectory and thereafter, attribute different functionalities to pauses, (2) understand how hikers of different age, gender, group size, or experience, partitioned their trajectories into pauses of different functionalities, (3) analyze the distribution of pauses of different functionalities at the landscape scale to provide managers with new suggestions on where to develop trails and for whom.

For the first step, we considered each trajectory as made of pauses and moves, and then focused on pauses only. To identify the "functional" role of pauses along a recovery to contemplation gradient, we made the important assumption that this role was not defined by a pause's duration per se, but by its ranking within each trajectory (from the longest to the shortest pause) and its position in the landscape. We first used the location of the longest pauses to identify the main sought-after areas in our study site, that should include the points of interest indicated on maps (mountain huts, passes and summits) as well as other less conspicuous areas. Then, we classified the pauses of lower ranks as close or far away from these sought-after areas, and proposed a classification of all pauses depending on both their rank and position relative to sought-after areas. Once all pauses were classified, we tested whether classes of pauses differed in terms of temporal characteristics (when they occurred during the day) and landscape characteristics (proxies of scenic beauty, slope, altitude). While the longest pauses should allow us to identify the "eye-catching" places, the location of low-ranking pauses far away from the scenic areas should inform us of the location and characteristics of "breath-catching places," which we expect to occur in the strenuous sections of trajectories.

The second step of our analyses was to determine whether pauses characteristics, accounting for our proposed typology, differed among hikers. To do so, we collated the pause dataset with hikers' individual or group characteristics obtained from a questionnaire, and tested whether the number of pauses in a trajectory, and pauses duration and location varied depending on individual gender, age, group size and composition, experience, and individual sensitivity to wildlife observation. Finally, based on the outcomes of these two steps (step 1: analysis of pauses spatio-temporal characteristics and proposition of a pauses typology, step 2: relationship between pauses and hikers characteristics), we adopted a more encompassing viewpoint of the combined trajectories at the study site level to identify clusters of pauses by their functionality at the landscape level. This exemplifies how studying pauses could help the development of tracks by, for instance, providing new agreable locations, at "breath-catching" places, that could also serve to transfer information to hikers.

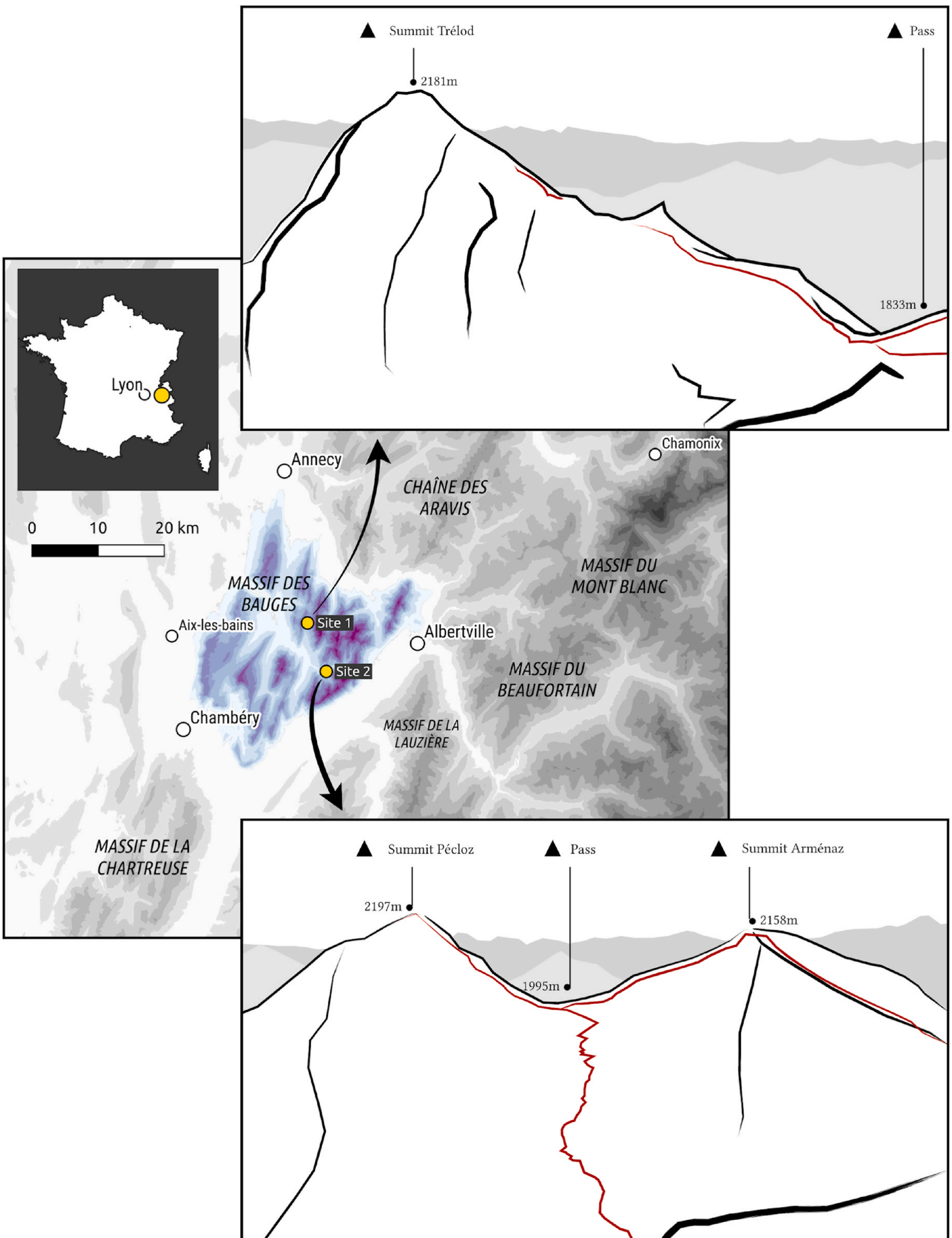

Fig. 1. Map of the study area with its location in France.

2. Material and methods

2.1. Study area

Our study site is a protected area within the "Parc Naturel Régional du Massif des Bauges", in the northern French Alps (45.65°N, 6.23°E). This mountain massif has a maximum altitude of 2200 m. The highest summits are mostly found in an area with a special protection status, a National Game and Wildlife Reserve (NGWR), where hiking off-tracks, bringing dogs along are prohibited and where hunting is allowed during the autumn (Courbin et al., 2022). The NGWR and its immediate surrounding cover 15600 ha. The most abundant large herbivores that can be observed above the treeline (Gruas, Loison, Ba, & Perrin-Malterre, 2023) are chamois (Rupicapra rupicapra) (Darmon et al., 2012; Duparc, 2016; Loison, Appolinaire, Jullien, & Dubray, 2006; Thuiller et al., 2018), and, to a lesser extent, mouflon (Ovis gmelini musimon), a species that has been introduced in the 1950ies (Darmon, Calenge, Loison, Maillard, & Jullien, 2007). Roe deer, red deer and wild boar, although present, are rarely observed by hikers as they mostly occupy forested areas (Gruas, Loison, Ba, & Perrin-Malterre, 2023). We focused on two networks of trails in the NGWR, called thereafter Site 1 and Site 2, each of them corresponding to a parking lot used as the main trailhead for hikers to reach several summits >2000 m (Site 1: Trélod at 2180m; Site 2: Pécloz at 2200 and Armenaz at 2180 m). Trails start at relatively low altitude (900 m), wandering through the forest, before reaching alpine pastures at higher altitude (ca. 1600 m). Trails are not larger than 1 m all along the first site, but the first part (ca. 1600 m) of the hike is larger for the second site. There is no specific trail surface materials set on both sites. The scenery from the highest peaks encompasses the highest peaks of the Alps, among which the Mont-Blanc. We identified 4 (Site 1) and 5 (Site 2) possible points of interest (POI) that could be targets for hikers, such as summits, building (mountain huts) and passes (Fig. 1). There are no mountain huts or opportunities to purchase food at either site.

2.2. Data collection and trajectory attributes

During summers 2014 and 2015, we asked hikers to carry a gps tracker IgotU GT-120 during their activity, and to answer a sociological questionnaire once their hike was over. Questionnaires aimed to get information about the composition of the hikers' groups, a socio-demographic description, their motivation, their knowledge of wildlife and site regulations. When hikers were not alone, only one of them carried a GPS but questionnaires were distributed to all members of the group. The trajectory was associated with the whole group, and not the carrier of the tracker alone. We alternatively sampled the two sites on 21 days over the two summers (site 1 = 10 days, site 2 = 11 days), from 8:00am to 5:00pm.

The GPS devices were programmed to record fixes every 10 s. One trajectory corresponds to a series of fixes (linearly interpolated or not) from the GPS device for one carrier within one day. We collected 282 GPS tracks on the two sites. We used 109 GPS trajectories out of these 282 tracks, selecting only those going further than 2 km from the trailhead, and intersecting the two alpine pastures from sites 1 or 2 (Fig. 1). We estimated a mean error of 19.35 m for the trajectories (95% of the raw data), error being calculated as the mean distance to the hiking path. Since some GPS-trackers were returned without hikers being willing or having time to answer the questionnaires, we could only use 69 groups questionnaires to combine the socio-demographic data to the trajectory dataset.

Trajectories attributes were calculated from GPS data (duration of the hike, hour at departure and arrival). Based on the questionnaire, we kept the following variables: group age, group size, gender diversity (men only, women only, mixed group), observation of wildlife during the hike (yes or no) and if hikers did pause or not for observing wildlife. Given that few respondents observed wildlife, we aggregated the two last answers into 3 categories:" long pauses (>10 min) for observation of wildlife"," short (>3 min) or no pauses when encountering wildlife", "no wildlife encountered." For group age, we combined age data of members of the group (minimum, maximum and mean ages), into a unique variable calculated from a hierarchical clustering, and aggregated for middle age groups (Appendix 1).

2.3. Processing of GPS data, identification of pauses and pauses' attributes

Within each trajectory, we considered that pauses were GPS points that were spatially and temporally clustered. We used the density-based clustering method ST-DBSCAN to detect the pauses (Birant & Kut, 2007). This method is a temporal update of the DBSCAN algorithm (Ester, Kriegel, Sander, & Xu, 1996) which is largely used in spatial clustering applications (McArdle et al., 2014; Tietbohl et al., 2008). ST-DBSCAN parameters are the same as DBSCAN: neighborhood maximum distance (Eps) and the minimum number of GPS points in a pause (MinPpts), to which is added a temporal window (Eps2) in order to discriminate spatially closed though temporally far points. The ST-DBSCAN algorithm sensitivity has been previously tested with several parameter values combinations (Kerouanton, Duparc, Jolivet, Perrin-Malterre, & Loison, 2017; Kerouanton, 2020) and compared with a defined expert truth. Based on this study, we applied a combination of parameters which has a probability of error for detecting hiker pause (superior to 3 min) less than 9%. Here, we consider a hiker pause as a place where a hiker would stop for more than 3 min. The parameter minPts has been set to 17 GPS points, eps to 6 m, and eps2 to a temporal window of 500 s. We defined a medoid to every cluster detected as a pause in order to handle one representative point for a set of points. A medoid is a point attribution for the nearest GPS recorded point to the median of the GPS points within the cluster. We aggregated iteratively all pauses detected from a same trajectory which are located less than 60 m and less than 4 min apart from each other, to account for GPS-errors. Every pause, located by its medoid, was associated with temporal and geographical metrics. The temporal metrics were GPS trajectory id, starting time, ending time, duration, when it occurred during the day (hour), and when relative to the whole duration of the trajectory (in percentage of the total duration). Each pause was also ranked by decreasing duration within a trajectory. To get geographical variables at the location of each pause, we used the DEM to extract the altitude, the slope value, and a visibility index at the medoid. We defined the visibility index as the total surface of pixels seen from the pixel corresponding to the location of a pause. Computing was made with the viewshed function of Pixscape software (Sahraoui, Vuidel, Joly, & Foltête, 2018). Inputs were a sampling grid on study sites, the DEM (5 m resolution) limited to 70 km around the hiking sites, and the vegetation map parameterized with a forest height equal to 15 m. We then interpolated visibility values (width = 5 m) with QGIS program. We also calculated the spatial proximity of pauses to the points of interest identified on the 2 study sites (summits, pass, mountain huts, Fig. 1).

Once all pauses in a trajectory and their associated spatio-temporal metrics were identified, we also estimated two metrics at the trajectory level: the total hike time spent in pause and the number of pauses.

2.4. Defining categories of pauses and their spatio-temporal characteristics

As explained in the introduction, we proposed an a priori typology of pauses within a trajectory based on both pauses rank and their position relative to the identified locations of all longest pauses in our data set. We assumed that the longest pause of a trajectory (pause of rank 1, thereafter denoted P1) should allow us to identify the sought-after areas in the landscape, i.e. those where hikers aim to end up for enjoying the view and/or their achievement, share a moment with other participants, or rest after a difficult physical effort. Whether other pauses are located

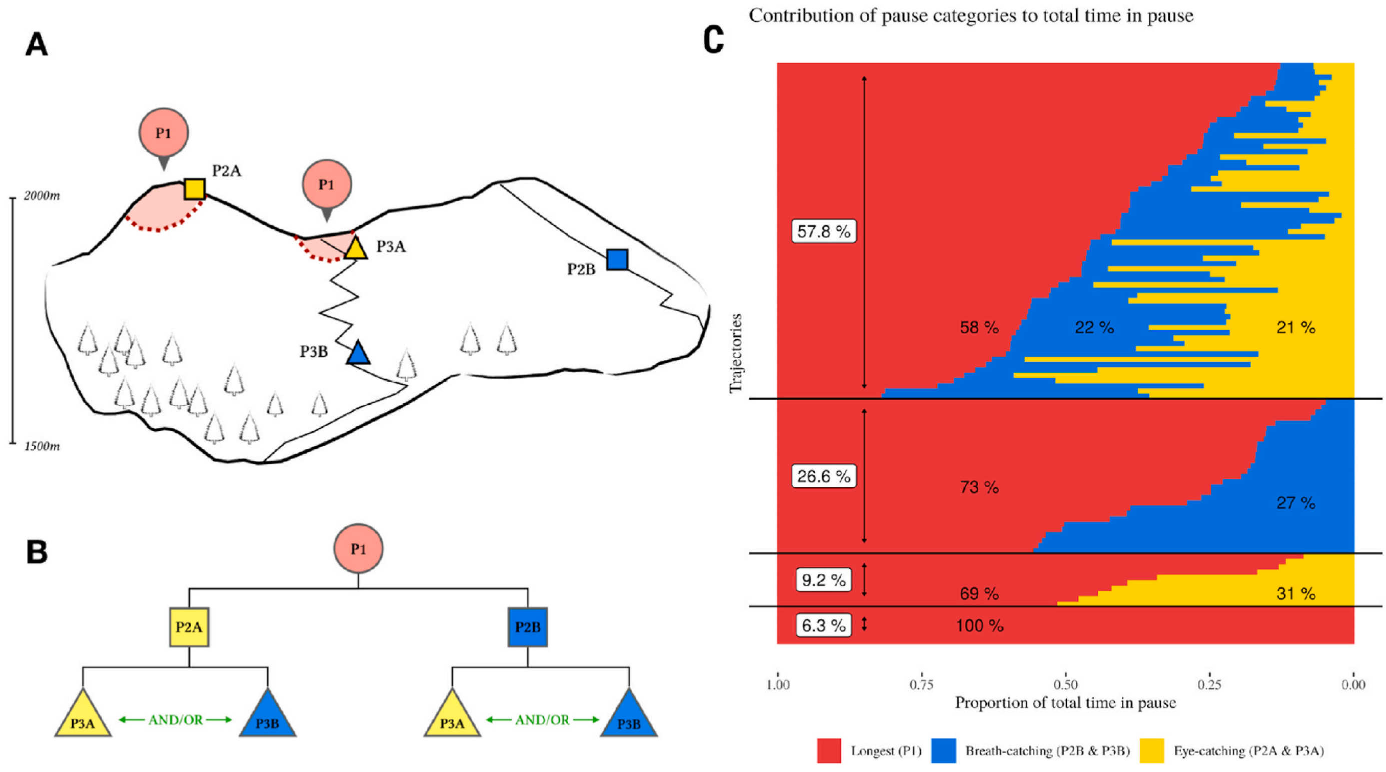

Fig. 2. (A) Schematic representation of pause by category. P1: longest pause, red circle; P2: second longest pause, square-yellow for P2A, i.e. close to P1s locations, blue for P2B, i.e. far away from P1s locations; P3: other pauses, triangle - yellow for P3A, i.e. close to P1s locations, blue for P3B, i.e. far away from P1s locations; (B) Schematic diagram displaying the possible combinations of pauses categories. Every trajectory has a P1, but can only have a P2A or a P2B, and possibly several P3A and P3B pauses. (C) Proportion of the total duration of pauses spent in the main pause P1, in eye-catching pauses (P2A and P3A, in yellow) and in breath-catching pause (P2B and P3B, in blue). We provide the percentage of trajectories for trajectories with only a P1, a P1 and eye-catching pauses only, a P1 and breath catching pauses only, a P1 and both eye-catching and breath catching pauses. For each of these groups of trajectories, we also give the average percentage of total pause time spent in each pause category (dark red: in P1, darkblue: in breath-catching pause; grey: in eye-catching pause).

in these sought after areas should therefore help us identify whether the other pauses are "eye-catching" pauses, or "breath-catching" pauses. In the following and for the sake of simplicity, we noted P1 the longest pause, P2 the second longest pause and P3 all pauses of lower ranks. Having identified P1s and their location, we then split pauses of lower ranks depending on their distance to any P1 location (all trajectories' P1s), calling P2A and P3A pauses that were close to a P1 location, and P2B and P3B all other pauses that were further away from any P1 location (Fig. 2A). We defined a threshold distance of 30 m to split pauses as close to P1 or further away, based on the distribution of distance between P1 and either P2 or P3 (Appendix 2A). We repeated the analyses described below with other threshold values (20m, 50m) to check that the main patterns were robust regarding these threshold values (see Appendix 3 for Fig. 4- from the result section-drawn with 20m and 50m for a comparative purpose). We hence ended up with 5 categories of pauses (P1, P2A, P2B, P3A, P3B) using 2 criteria (rank based on duration, and proximity to P1 location). Note that while a given trajectory can only have one P1 and either one P2A or one P2B pause, it can have several P3A or P3B (Fig. 2B).

Since our goal was to determine if our classification of pauses corresponded to a functional role as "breath-catching" or "eye-catching," we investigated the differences among pauses categories for a set of variables (pauses' temporal and landscape attributes): hour, duration, slope, visibility, altitude, distance to POIs. For the latter variable, we estimated the distance between each P1 location and the points of interest (summits, paths, and mountain huts), and considered that a pause occurred at a POI if it was located within 30 m of a point of interest. This threshold was chosen both from the distribution of pauses distances to POIs (Appendix 2B) and for consistency with the threshold chosen above. Given that our typology of pauses was based on rank and relative proximity to P1, some trivial results were expected on duration and position: P1 should be on average longer than P2 and P3, and, if P1 locations are close to POI, then P2A and P3A should also be closer to POIs than P2B and P3B. In addition, as formulated in introduction, we expected P2B and P3B to be mostly in strenuous parts of an itinerary (steep slope, medium altitude).

We performed a between-class Principal Component Analyses (bPCA, Doledec & Chessel (1989)) with altitude, slope, visibility, proximity to a summit, and proximity to a pass as environmental variables, and pause categories as classes, whereby a permutation tests allowed testing whether the different categories of pauses explained a significant component of the PCA inertia (Figures and permutation test provided in Appendix 4).

We then tested for differences in all the spatio-temporal variables detailed above according to pauses typology. Hence, we performed generalized linear mixed models, with each spatio-temporal variable as a response variable, pause typology as a fixed explanatory variable, and trajectory ID and Site as random variables. For the sake of normality, we log-transformed the duration variable, and we logit-transformed visibility. For the proximity to POI variable, we used generalized linear mixed models with binomial family. We performed post-doc multiple comparisons between the different pauses categories using Tukey pairwise comparison tests.

2.5. *Distribution and characteristics of pauses by hiker parties' profile*

As a second step, we aimed at determining if hikers' sociodemographics and characteristics of pauses were related. We expected the total duration of pauses, the proportion of time spent in pause, the duration of the different categories of pauses (P1, eyes-catching pauses P2A and P3A, and breath-catching pauses P2B and P3B) and the number of pauses to differ among hikers. Some of these variables were however strongly correlated (Appendix 5), such as the number of pauses and the total duration in pause or the proportion of time in pause, so we ran the models on the number of pauses only. We also tested whether the probability to make an eye-catching pause or a breath-catching pause to vary among hikers. The variables taken into account were group size, fitness level (quantified here through the frequency of practice), gender classes, age classes. We log-transformed pause duration and logit-transformed the proportion of the total hike spent in pause for the sake of normality (then used linear model), while the number of pauses was analyzed with a Poisson distribution and the probability to perform an eye-catching pause or a breath catching pause was analyzed with a binomial distribution.

2.6. Spatial distribution of pauses at the site level

As a last part of our study, we performed a site-level analysis of pauses location. Based on the location of all pauses we identified clusters of places of pauses. Those places are defined as areas where at least 5 hiker groups have stopped. We used DBSCAN in order to detect spatial clusters of GPS points, all trajectories combined. DBSCAN parameters were set with less restricted values: eps = 25 m and minPts = 7 than when we sought to identify pauses in a trajectory. We then applied a convex envelope on the spatial clusters medoids to delimitate areas that correspond to the clusters of pauses. All statistical analyses were performed with R version 3.6.1 (2019-07-05) using package lme4 when running mixed effects models (Bates et al., 2019) and the multcomp package for multiple comparisons of pauses categories (Hothorn et al., 2016). Means of each variable are provided with standard errors.

3. Results

3.1. Descriptive statistics of trajectories

We detected 510 pauses from the 109 GPS-trajectories collected on Sites 1 and 2. Hikers had similar hours at departure in Site 1 and Site 2, but their hike differed by their distance, duration, and pauses durations (Table 1). Hikers made less pauses on Site 1 than on Site 2 (4.1 ± 0.25 vs 6.1 ± 0.60 pauses). Only 6.3% of the hiker parties made only one pause (Fig. 2C). The remaining parties took between 2 and 13 pauses. 9.2% parties made only P2A or P3A pauses (of “eye-catching” type, see Table 1), 26.6% only P2B or P3B (of “breath-catching” type, see Table 1), and 57.8 % both types of pauses (Fig. 2C).

Table 1
Summary statistics for the trajectories collected by GPS-trackers for the two study sites (Mean and standard errors [min; max]). The contrast between Sites was tested for pause duration with a *t*-test of log-transformed pause duration.

	Site 1	Site 2	Test (for pause duration)
Nb GPS tracks	77	32	
Mean hour departure	09:30 [06:52; 12:15]	09:45 [08:17; 14:12]	
Mean hour arrival	15:22 [11:27; 17:39]	15:58 [13:37; 19:02]	
Mean hour P1	12:11 [09:00; 15:57]	12:50 [11:32; 16:44]	
Hike duration (hour)	5.9 ± 0.2 [2.0; 9.4]	6.2 ± 0.24 [3.1; 8.6]	
Hike distance (km)	14.5 ± 0.24 [10.6; 21.3]	15.5 ± 0.44 [11.2; 20.5]	
Nb pauses	4.1 ± 0.25 [1; 13]	6.1 ± 0.6 [1; 13]	
Hike time in pauses (%)	21.4% ± 0.01 [3.4; 50.1]	19.3% ± 0.01 [3.4; 33.7]	
Duration P1 (min)	52.3 ± 3.1 [4.7; 141.2]	39.8 ± 4.5 [10.0; 101.5]	$t = -1.96$, $P = 0.05$
Duration P2A (min)	15.7 ± 1.9 [3.3; 54.0]	15.4 ± 1.6 [5.5; 24.8]	$t = 0.69$, $P = 0.49$
Duration P2B (min)	13.2 ± 1.7 [3.0; 33.8]	8.8 ± 0.1.7 [3.3; 19.5]	$t = -1.24$, $P = 0.22$
Duration P3A (min)	7.5 ± 0.8 [3.0; 31.2]	7.4 ± 0.8 [3.0; 18.5]	$t = 0.31$, $P = 0.76$
Duration P3B (min)	5.2 ± 0.3 [3.0; 17.3]	5.3 ± 0.3 [3.0; 17.2]	$t = 0.57$; $P = 0.57$

3.2. Temporal and landscape characteristics of pauses classified by rank and position

The longest pause (P1) lasted 48.6 min on average (Fig. 3), being longer on Site 1 (52.3 ± 3.1 min) than on Site 2 (39.8 ± 4.5 min, see Table 1 for tests), though they represented similar proportions of the total time in pause in each site (56% on Site 1, 53% on Site 2 on average). Most of the longest pauses P1 (64%) were located within 30 m of a POI, mostly in the vicinity of summits (58%, Fig. 3E), less so in the vicinity of passes (4%, Fig. 3F) or mountain huts (2%, not represented). P1 pauses were located above 2000m on average (2088.93 ± 17.06 m, Fig. 3B), and on relatively shallow slopes (18.52 ± 1.01°, Fig. 3C) and in high visibility spots (73.98 ± 2.36% Fig. 3D). Most of them (64.6 ± 22.1%) occurred between 12 a.m. and 2 p.m.

Pauses of rank 2 (P2) were slightly longer when close to a P1 (P2A: 17.69 ± 1.52 min) than further away (P2B: 12.15 ± 1.17 min, pairwise comparison marginally significant, $P = 0.07$, see Table 2 for detailed tests, Fig. 3A). P3 pauses differed depending on their relative position to P1, P3A lasting longer (7.78 ± 0.76 min) than P3B (5.51 ± 0.21 min; Table 2, Fig. 3A). Duration of pauses P2 and P3 did not differ by Site (tests in Table 1).

As expected from how we defined them, P2A and P3A shared some of P1 landscape characteristics, such as the proximity to POIs (49% and 54% respectively), relatively high altitude and visibility, and shallow slopes (Fig. 3B–D, Table 2 for pairwise comparisons). Yet, P3A were lower in altitude (1945.57 ± 33.46 m) and on spots with less visibility (52.55 ± 5.06% of the highest visibility) than P1 (see values above) or P2A (altitude: 2049.44 ± 35.21 m, visibility: 64.85 ± 5.44%)- Fig. 3. P2A and P3A were actually on similar slopes (P2A: 16.06 ± 1.86°; P2B: 16.05 ± 1.39°).

Pauses of categories P2B and P3B had similar landscape characteristics one to another (altitude: P2B: 1798 ± 31.01 m; P3B: 1723.66 ± 17.99 m; visibility: P2B: 42.50 ± 3.38%; P3B: 35.37 ± 1.77; slope: P2B: 23.80 ± 1.43°; P3B: 24.52 ± 0.63°), but differed significantly from P1, P2A and P3A for these characteristics (see Table 2 for multiple post-doc comparison tests, Fig. 3).

The temporal and landscape characteristics of pauses validated that shortest pauses P2B and P3B were breath-catching pauses located in difficult sections of the itinerary. For the sake of simplicity, we positioned the different pauses on a slope vs visibility figure and on a proximity to a summit vs proximity to a pass figure (Fig. 4 - see Appendix 4 for the positioning of the pauses by category on the between-PCA map). These figures clearly highlight that P1, P2A and P3A share “eyes-catching” characteristics, on shallow slopes with high visibility, close to POIs and P2B and P3B share “breath-catching” characteristics on steep slopes with low visibility, further away from POIs (see also Fig. 6).

3.3. Sociological differences on spatio-temporal patterns of pauses

The number of pauses, the duration of the longest pause P1 and the duration of breath catching pauses (for groups that took the latter) all increased with group size (Table 3). For instance, largest groups made on average 3.4 more pauses and spent 40 min more in pause than single individuals (Fig. 5). The duration of breath-catching pause actually increased by group size only among parties with people practicing during holidays only, but frequent hikers in any group size had similar

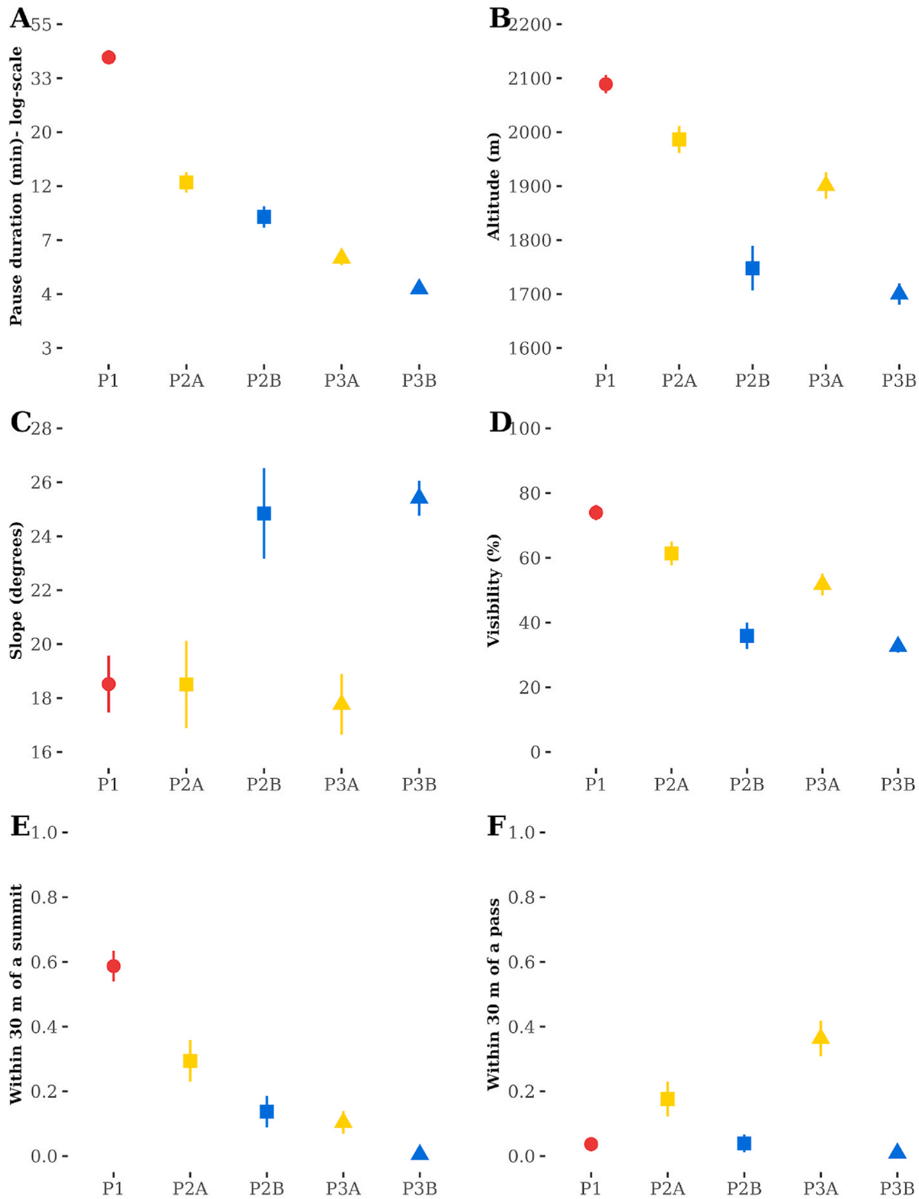

Fig. 3. Pauses characteristics (±se) by pause category. (A) Duration (log-scaled); (B) Altitude; (C) Slope; (D) Visibility; (E) Proportion of pauses within 30 m of a summit; (F) Proportion of pauses within 30 m of a pass.

duration of breath-catching pauses (12.2 min, between 9.9 and 16.6 min, Fig. 5). Single holiday practitioners actually had shorter breath-catching pauses (5.6 min of cumulated duration of breath-catching pauses) than single frequent hikers (16.6 min). Interestingly, group size did not play a role in the probabilities for a party to make an eye-catching or a breath catching pause (see Fig. 5).

These probabilities were influenced by the age typology of a group: families made less eye-catching pauses (51%) than all other groups (93%, 86% and 91% for Middle aged, Old, and Young groups respectively-predicted values for mixed-gender groups), while Middle-aged parties were less prone to make breath catching pauses (72% vs 100% for families and old groups and 94% for young groups, Fig. 5). Overall, young and old groups were the ones taking the largest number of pauses (7.9 and 6.5 pauses respectively, vs 5.0 and 5.5 for families and middle aged groups-predicted values for group size between 3 and 5), taking both eye and breath-catching pauses (Table 3, Fig. 5). Group gender composition was of little influence on pauses statistics, though mixed-gender groups were more prone to make eye-catching pauses than men-only groups (93% vs 72 % respectively, for middle age groups for instance) and stopped for a shorter duration when taking breath-catching pauses (14 min vs 26 min respectively-predictive values for groups of 3–5 persons of frequent hikers, Table 3, Fig. 5).

The frequency of practice was only retained in the best model for the duration of the breath catching pauses, in interaction with group size (Table 3). As explained above, this was displayed by a group size effect on breath catching pause duration only among groups with holiday-only practitioners (Fig. 5).

None of the pause statistics varied depending on whether groups had seen wildlife and whether they declared having stopped for a short or a long time (models where wildlife encounter was added to the best models were never within 2 units of AIC of the retained model, hence are not included in Table 3).

3.4. *Identification of pauses hotspots*

Sixteen clusters of pauses were detected with DBSCAN, 8 on each site. These clusters enveloped about half of the pauses (251 of the 510 pauses), and 72% of pauses >10 min. The total surface of these 16

Table 2
Post-hoc pairwise comparisons among the different categories of pauses for temporal and landscape characteristics. Z-score and P values (in brackets) from Tukey pairwise comparisons based on linear mixed models (with pause category as a fixed variable, and trajectory ID and Site as random effect variables) are provided for Duration (log-transformed), Slope, Altitude and Visibility (logit-transformed). Bold text cells correspond to non-significant Z-score tests.

		P1	P2A	P2B	P3A
Duration	P2A	−13.74 (<0.01)			
	P2B	−16.94 (<0.01)	**−2.60 (0.07)**		
	P3A	−25.54 (<0.01)	−8.34 (<0.01)	−5.30 (<0.01)	
	P3B	−36.35 (<0.01)	−12.73 (<0.01)	−9.17 (<0.01)	−3.65 (<0.01)
Slope	P2A	**0.01 (1.00)**			
	P2B	3.58 (<0.01)	3.03 (<0.01)		
	P3A	**−0.47 (0.99)**	**−0.40 (0.99)**	−3.73 (<0.01)	
	P3B	5.70 (<0.01)	4.28 (<0.01)	**0.40 (0.99)**	5.57 (<0.01)
Altitude	P2A	**−2.59 (0.07)**			
	P2B	−8.30 (<0.01)	−4.81 (<0.01)		
	P3A	−4.81 (<0.01)	**−1.55 (0.52)**	3.76 (<0.01)	
	P3B	−12.76 (<0.01)	−6.53 (<0.01)	**−0.68 (0.96)**	−5.93 (<0.01)
Visibility	P2A	**−2.06 (0.23)**			
	P2B	−7.27 (<0.01)	−4.34 (<0.01)		
	P3A	−3.53 (<0.01)	**−1.00 (0.85)**	3.82 (<0.01)	
	P3B	−10.73 (<0.01)	−5.88 (<0.01)	**−0.26 (0.99)**	−5.53 (<0.01)

clusters is 5946m2. Considering that a majority of pauses and 72% of long pauses are located on less than 6000m2 across the two study sites, we interpret this as an evidence for hotspots or centers in spatial patterns of pauses, scattered along the hiking paths.

4. Discussion

4.1. The role of pauses in a mountain hike

Mountain hiking is strenuous and, yet, rewarding for hikers. It provides a complex physical and emotional experience (P. J. Brown, 2019; Syarstad, 2010), intertwining enjoyable with physically taxing moments. We contend here that hiking trips can also be deciphered through a pause perspective, not only a moving one. Indeed, pauses are where relaxing, scenic moments are experienced (Kaplan, 1979; Martin et al., 2020; Ulrich, 1986), while also revealing where the physical constraints imposed by the arduous terrain on hikers are greatest. While the allocation of time to the longest pause and other scenic pauses can result from a choice made by a party ahead of a hike or on the spot, the allocation of time to pauses imposed by the lack of fitness of an individual or his/her hiking companions, may come as a capacity or coupling constraint rather than a choice (Hägerstrand, 1970b). These constraints can negatively impact the enjoyment derived from a hike. For instance, a too high intensity can decrease the pleasure drawn from an exercise (Ekkekakis, Parfitt, & Petruzzello, 2011). Below, we discuss our definition and methods to identify pause functionalities. We then delve on the landscape attributes of pauses of different functionalities and interpret the differences in the pause composition of each trajectory by socio-demographic characteristics of hikers group. Last, we postulate that identifying the distribution of both eye-caching and breath-catching pauses should help informing different groups of hikers of the difficulty they may encounter and where, and possibly help managers to develop better hiking information, so that breath-catching pauses may become enjoyable landmarks and intermediate goals, and less a constraint and burden for those that engage in an arduous hike.

4.2. Range of pauses detected by our methodological approaches

We chose a trajectory approach for our analyses, which views the itinerary of a hike as a set of pauses and moves (Alvares et al., 2007; Spaccapietra et al., 2008). We decided to detect pauses with ST-DBSCAN which is simple, fast to implement, and produces robust spatio-temporal clusters (when the minPts criteria is high). Therefore, we applied the algorithm with the same parameters on the whole dataset that have GPS tracks with different speeds. In the future, this approach could be improved by adapting parameters (Karami & Johansson, 2014; Li, Liu, Tang, & Deng, 2018) to trajectories metrics such as speed, mean distances, sinuosity, slope. ST-DBSCAN runs with spatio-temporal points, which have to be regular. Irregular GPS timestamps would make ST-DBSCAN use irrelevant as it is only based on points density. Due to our choice of parameters, we detected pauses above a threshold of 3 min. Decreasing this threshold may increase the likelihood of identifying artefact pauses, given the error of GPS fixes and the winding nature of tracks in mountains, especially in steep sections. Given the fast-increasing reliability and precision of GPS-trackers though, better assessment of very short pauses may be possible in the future. Pauses shorter than 3 min may be breath-catching pauses for single hikers that do not need to wait for slower members in a group, or for parties composed by fit-only hikers. While these pauses may have the same functionalities for fit hikers as short but >3 min pauses for less fit hikers, they would not contribute to a high proportion of the total time in pause.

4.3. Breath-catching pauses: a neglected component of a hiking trip

One of our main choices to find differences among pauses characteristics was to perform a ranking of the pauses by their relative within-trajectory duration, rather than considering pauses by their duration over the whole dataset. In addition, we segregated pauses not only by their rank, but also by their position relative to the location of all longest pauses in the dataset, our main goal being to test a posteriori that our categories were meaningful in terms of functionality and landscape characteristics. With this viewpoint, we showed that the duration of the pauses of ranks ≥ differed depending on where they were in relative to the longest pause, and were therefore shortest when in steep slopes where visibility is low. We interpret this as signifying that these pauses were mostly not taken for pleasure, but as a response to the GPS-carrier physical limitation or the waiting of other members of the group. We did not find any other internationally published study estimating the contribution of such pauses to the total amount of pause duration during an outdoor activity. Surprisingly, the cumulated duration of such breath-catching breaks made up about one quarter of pause time, an amount that could go up to half of their pause time (Fig. 2). When planning ahead, hikers may be aware of how fast they hike uphill and downhill on average (most probably breath-catching pauses included), but it would be interesting to delve deeper on hiker awareness of the time taken moving versus stopping, and to better grasp whether such pauses are seen as a burden and a displeasure, and are considered as an unavoidable and well-accepted part of a hike in the mountain. Indeed, prior knowledge of a route difficulty may be key for hikers to engage in an itinerary (Hugo, 1999; Slabbert & Du Preez, 2017). We also surmise that one could be aware of one's need for breath-catching pauses, but less so of the need for others in their group. If short pauses in steep slopes are also moments to wait for others in a group (Schamel 2015 in Schamel and Job (2017a)), this could lead to tensions and impact group cohesion, a primary determinant of safety in mountains (De Decker, Tölken, & Roos, 2017). We grouped all pauses (of rank ≥ 2)away from scenic areas as "breath-catching" pauses whatever their within-trajectory ranking.

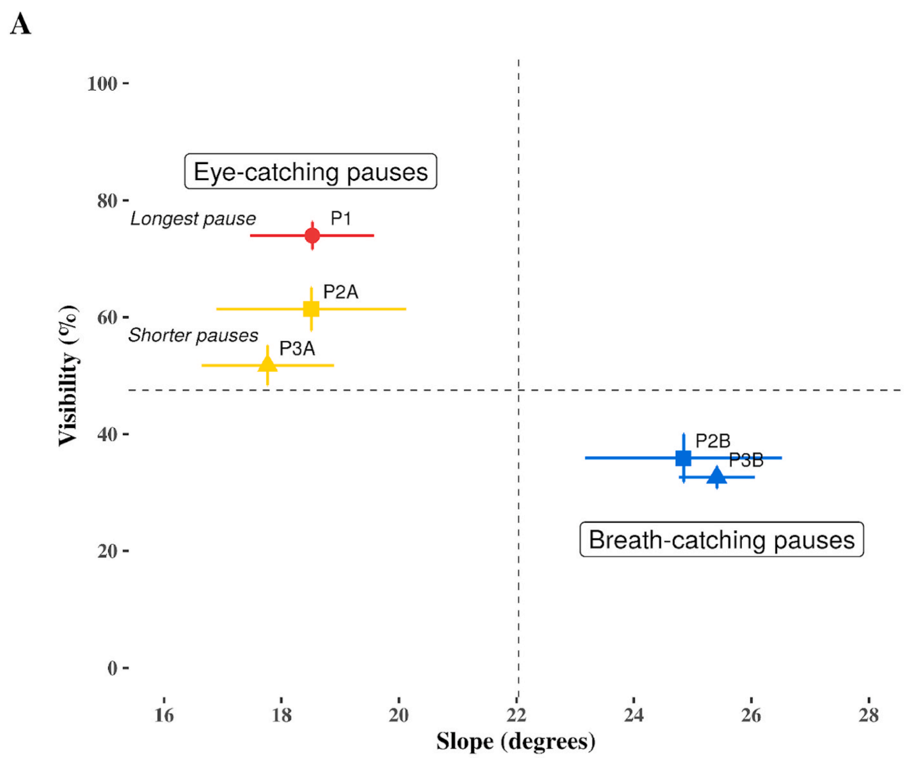

Fig. 4. Pauses categories positioned according to(A) average slope (±se) and visibility (±se) and (B) Probability to be within 20m of a top vs probability to be within 30m of a pass. Vertical and horizontal dashed lines indicate the average values X and Y axes over all pauses. Shapes correspond to pause ranking (circle = P1, square: P2, triangle: P3) and colors to the position relative to P1 (red: P1, yellow: close to P1, blue: far from P1) – see Fig. 2.

This grouping was supported by the surprisingly similar landscape characteristics among these pauses (similar slope, visibility and altitude, Fig. 4).Yet, the duration of such pauses that we interpret as pauses imposed by the interaction of terrain, group dynamics, and people fitness, lasted about 10 min on average, and up to 33 min. It is likely that the longest of these pauses may be breaks made voluntarily (i.e. independent of hiker's fitness or group dynamics), for instance in case of windy weather, cloudy summits, or overcrowded tops or passes. The circumstances during which the longest of these breath-catching pauses of rank ≥ 2 occur and their function within a group's hike need to be

Table 3
Model selection for 6 pause variables (Number of pauses, Total duration, Proportion of time in pause, Duration of P1, Duration of eye-catching pauses, Duration of breath-catching pauses) with group size ("Size": 4 categories), age group ("Age": 4 categories), frequency of practice ("Frequency": 2 categories), gender group ("Gender": 2 categories). Number of pauses was analyzed with a Poisson generalized linear model. Durations were log-transformed and the proportion of time in pause was logit transformed. AICc = corrected Akaike Information Criteria; K = degrees of freedom; dAICc = difference between a model's AICc and the lowest AICc; AICcw = weight of the model within the set of tested models. All models dAICc <2 are included in the Table, as well as null models.

Response variable	Model	K	dAICc	AICcw
Number of pauses	**Size + Age**	**7**	0.00	0.26
	Size + Age + Frequency	8	0.77	0.17
	Size x Frequency	8	1.02	0.15
	Size	4	1.67	0.11
	Null	1	2.85	0.06
Total duration of pauses	**Size + Age**	**8**	0.00	0.29
	Size + Age + Gender	9	0.11	0.28
	Size + Age + Gender + Frequency	10	1.77	0.13
	Size + Age + Frequency	9	1.97	0.12
	Null	2	4.19	0.04
Duration of P1	**Size + Age**	**8**	0.00	0.23
	Size	5	0.46	0.18
	Size + Gender	6	1.26	0.12
	Size + Age + Gender	9	1.30	0.12
	Null	2	1.52	0.01
Probability of eye-catching pauses	**Age + Gender**	**5**	0.00	0.41
	Age + Gender + frequency	6	1.05	0.25
	Null	1	2.17	0.14
Duration of eye-catching pauses	**Null**	**2**	0.00	0.34
	Frequency	3	1.00	0.22
	Size	5	1.03	0.21
	Size + Frequency	6	1.77	0.15
Probability of breath-catching pauses	**Age**	**4**	0.00	0.33
	Age + Frequency	5	0.43	0.26
	Age + Gender	5	1.13	0.19
	Null	1	4.66	0.03
Duration of breath-catching pauses	**Size x Frequency + Gender**	**11**	0.00	0.27
	Size + Gender	6	1.01	0.16
	Size + Frequency x Gender	8	1.47	0.13
	Frequency x Gender	5	1.86	0.11
	Null	2	3.85	0.04

explored further, in a group dynamics perspective, a time-budget approach (within the time-geography framework, Hägerstrand (1970b) and Schamel and Job (2017a)), as well as from a terrain point of view. New more focused questionnaires, interviews, or other investigating approaches (e.g. on-board experience sampling methods (Doherty, Lemieux, & Canally, 2014), shared experience (Chanteloup, Perrin-Malterre, Duparc, & Loison, 2016), mobile ethnography (K. M. Brown, 2017)) would be most helpful in this context.

4.4. Eye-catching pauses: homogeneous landscape characteristics but different positions relative to the points of interests

Given how we segregated the pauses of ranks ≥ 2, it was expected that pauses overlapping with any of the main pause locations (which we categorized as "eye-catching" pauses) were also situated on scenic spots. Yet, they differed in terms of distance relative to POIs. Summits are where most of the long pauses and second longest pauses occurred, while third longest pauses occurred closer to passes. That pauses occurred at such spots is no surprise. Hikers are attracted in mountain by landscape scenic values, best appreciated from location with long distance visibility (Schamel & Job, 2017a; Schirpke, Tasser, & Tappeiner, 2013a). Multiple summit edges influence human preference (Hammitt, Patterson, & NOE, 1994), as do scene complexity, coherence (Kaplan, 1979) and viewpoints (Ulrich, 1986). Ulrich (1986) and Kaplan (1979) both underlined the tendency to prefer landscape where users can imagine "what is beyond". Hammitt et al. (1994) used tests based on photos to explore those preferences, and our results from spatio-temporal GPS patterns support that landscape complexity is probably a pull factor for visitors. Places of high visibility were likely to be chosen for midday pauses when the longest pauses occurred. POIs may be conducive to contemplation, being part of the mountain aesthetic (Schirpke et al., 2013a). For Kaplan (1979), one of the argument for landscape preferences is also the tendency to legibility, which he defines as the feeling of safety on a landscape scene, i.e. where one knows and can see how to get there and come back. On our study sites, summits are located close to cliffs, with a steep and risky access (50°), where slipping could lead to serious accidents and death. The motivation to rest where seeing far away may drive hikers to overcome these risks in these sections, especially as once on the spot, slope is locally moderated. Giddy (2018) and Mackenzie and Brymer (2018) studying adventure-tourism in South Africa and New Zealand respectively, found that people were more attracted by connecting to nature and escapism from daily life than thrill and risk. We need to investigate more precisely whether different categories of hikers (age, gender, experience) are drawn to different eye-catching locations depending on not only their visibility and slope per se, but also depending on how difficult they are to reach. Notably, one third of the trajectories in our sample had no eye-catching pauses beyond the longest pause. This may result from the circumstances such as an unexpected bad weather for instance, or to the primary motivation of hikers, such as training, rather than escapism or connection to nature (Giddy, 2018). We also need to investigate other study sites as ours did not have any water landmark (altitude lake, river) nor altitude restaurant, where longest pauses could take place. Additionally, our study was only conducted on non-raining days, which is a bias on duration and location of eye-catching pauses. We could expect shorter eye-catching pauses on a raining day or with presence of mist, and we could also expect that landmarks seeked on such days could be different than on sunny days.

4.5. Hikers party characteristics influence pauses distribution and duration within a hike

Group size was determinant in the number of pauses detected and the duration of the main pauses. This is congruent with former empirical findings (e.g. Schamel and Job (2017a)) but also with the concept of time-geography and the coupling constraint (Hägerstrand, 1970b; Schamel & Job, 2017a). As the general population is ageing, so are people engaging in hiking in the mountains. While previous studies support that older people are generally slower than younger ones (Schamel & Job, 2017a) due to decreasing physiological capacities (Bohannon & Williams Andrews, 2011), our result do not support that this would be mediated by an increased number of pauses, or a longer duration of pauses in old groups rather than middle-aged or young groups. Yet, old groups were all taking breath catching pauses to a higher extent than middle aged or young groups. Despite previous findings that old people get more slowly, future study of aging on hiking should account for differences in hikers' time budget and allocation of type to pauses of different functionalities. One result that was surprising at first was that groups classified as families, compared to young, middle-aged, and old groups, were having a relatively lower number of pauses and shorter main pauses, and were all stopping in breath-catching pauses while stopping less often in eye-catching pauses. This may sound counterintuitive if families were adults with young children. In our sample, respondents were mostly adults with teenagers rather than young children (Appendix 1). This probably results from the difficulty of the tracks (steepness and length), which are not conducive

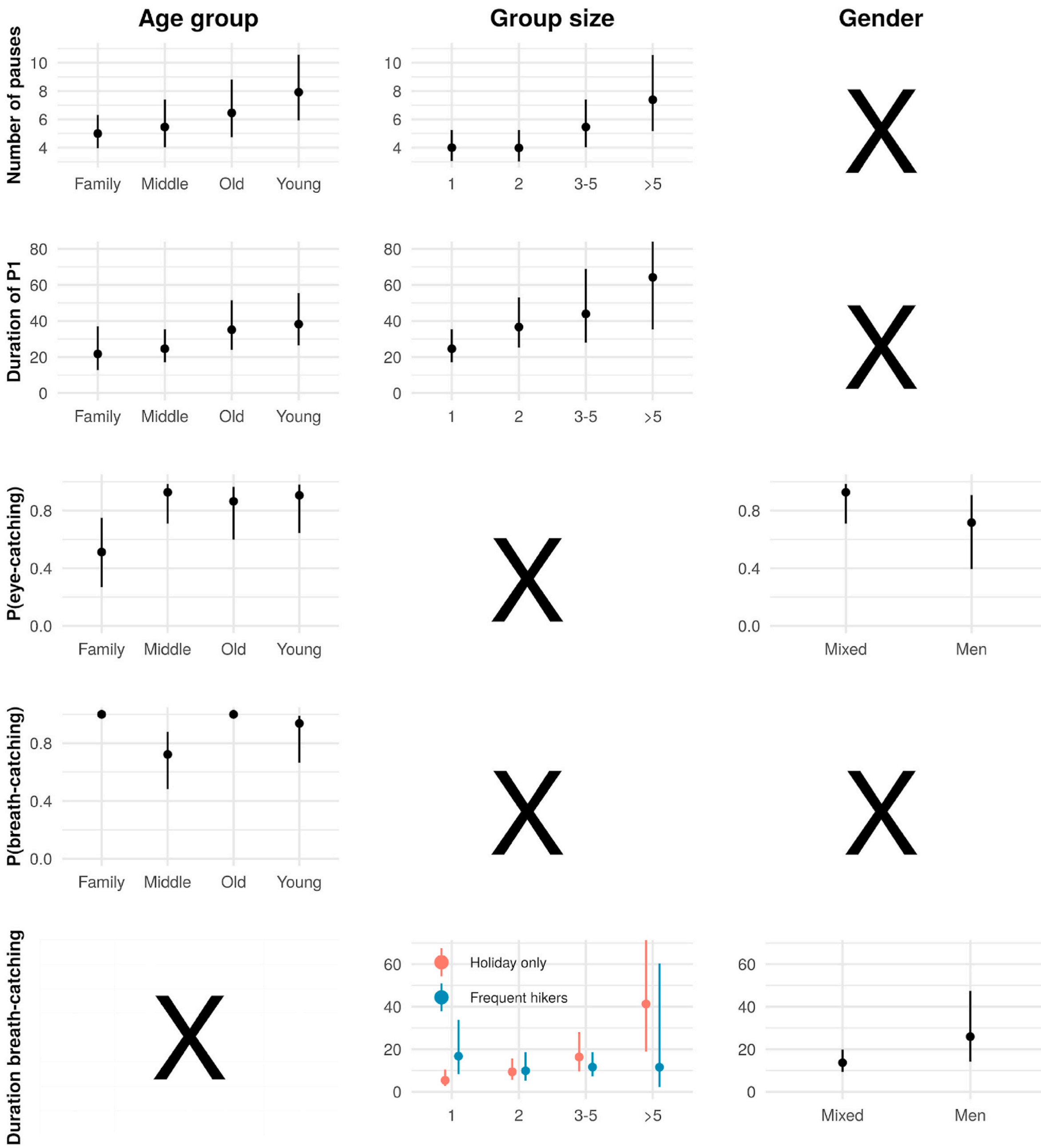

Fig. 5. Effects of Age group, Group size, and Group gender composition on the Number of pauses, Duration of the longest pause P1 (min), probability to make an eye-catching pause, probability to make a breath catching pause and duration of breath catching pauses (min). Predicted values from the retained model (Table 3) are displayed with the confidence interval of the predicted values. The panel is empty (a cross is displayed instead) for factors that had a non-significant effect on the response variable.

to bringing along young children. Processes of group dynamics in mixed aged-groups with teenagers and a heterogeneity in motivation and fitness may explain our results. Teenagers may be less prone to stay still during a pause once they are at destinations, and may be less willing than adults to make several scenic breaks along their way. While in families with young children, breath-catching pauses may be pauses where adults are waiting for the children, the reverse may be true when children are teenagers and may get fitter than their parents, grandparents, or guide. A focus on how groups with teenagers plan their hike and account for different motivation and fitness, how they manage their hike when on their itinerary, whether tension of conflict occur about hiking speed and pause duration, would be most interesting, especially in the light of studies that show that experiences gained during childhood are pivotal for explaining adult connectedness to nature and future participation to outdoor activities (Colléony, Prévot, Saint Jalme, & Clayton, 2017; Lovelock, Walters, Jellum, & Thompson-Carr, 2016). Future questionnaires have to be designed with questions on time-budget and planning, motivation, reasons for satisfaction and dissatisfaction during the hike such as crowding (Gruas, Perrin-Malterre, & Loison, 2022), fitness level, on both the individual carrying the GPS as well as members of the group for non-single hikers. Time budget time could be a good approach for establishing recreationist typologies, together with the GPS tool (e.g. Depeau et al. (2017)).

4.6. *Mapping pauses at the landscape levels and management implications of studying hikes from a pause viewpoint*

The clusters of pauses we detected can be considered as spatio-

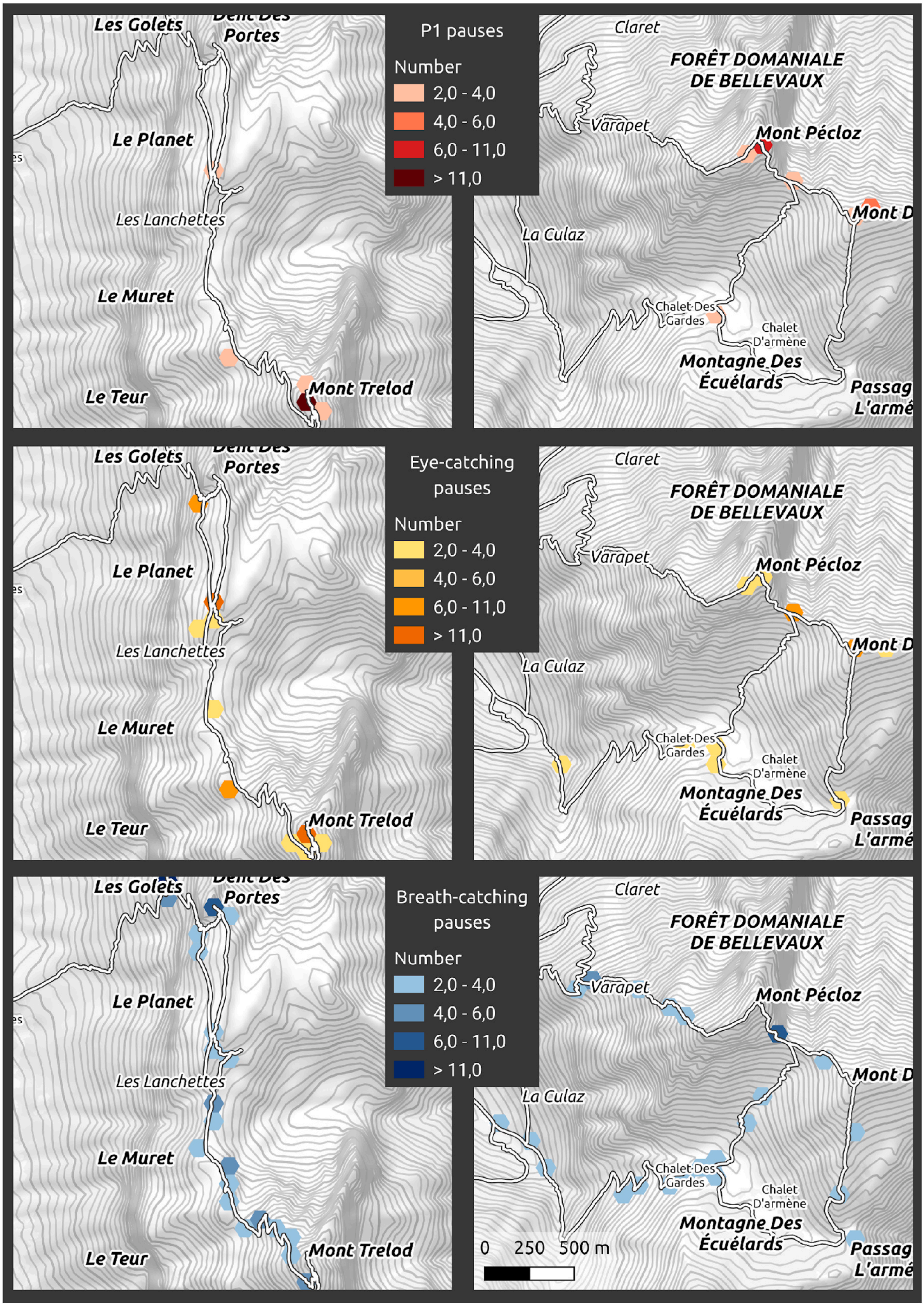

Fig. 6. Locations of the longest pauses (P1 in red), the eye-catching pauses and (in yellow) and of the breath-catching pauses (in blue) in the 2 study sites.

temporal hotspots of human activities in this natural area. Those hotspots could lead to some troublesome behaviors, or could be a concern for vegetation and wildlife (Lynn & Brown, 2003; Marion, 2023; C. A. Monz, Pickering, & Hadwen, 2013). The encountering of wildlife did not modify the general statistics of pauses (number, duration), hence the time-budget of hikers. However, the presence of hikers, while moving or pausing, may be influential on animal behavior (Geffroy, Samia, Bessa, & Blumstein, 2015) and impact vegetation and soils. Ecology studies pointed out that humans are perceived as predators by wildlife (Frid & Dill, 2002) and consequently induces a spatio-temporal response to human activities (Boyle & Samson, 1985) such as flight (Gander & Ingold, 1997; Stankowich, 2008), avoidance (Basille et al., 2009; Marchand et al., 2014) or stress (Creel et al., 2002). In our context, the human activity hotspots are located within chamois home ranges and results in chamois deserting the vicinity of trails when hikers arrive, changing their feeding habits (Duparc, 2016). A better prediction of how human activity distributes would be crucial to better understand wildlife spatial selection and behavior, along with the distribution of food and resting places. Furthermore, it could help management practice with the disposal of responsive hiking behavior panels on strategic places where a type of pauses could occur more often (Cremer-Schulte, Rehnus, Duparc, Perrin-Malterre, & Arneodo, 2017; Guo, Smith, Leung, Seekamp, & Moore, 2015; Winter, 2006). This better prediction could also give insights for practitioners in order to eventually set resting facilities. To estimate impact of human activities on their biotic and abiotic compartment of the mountain ecosystem, and to concile nature conservation with the development of outdoor activities (for the sake of economic development, or individual well-being), we now need to use empirical results, such as those obtained here, to build spatially-explicit models spatially of the behaviors of recreationists of different socio-demographic categories (see e.g. González, Hidalgo, and Barabási (2008), Pappalardo et al. (2015) and Taczanowska (2009)). Our hotspot detection approach could furtherly be associated with the carrying capacity concept (Job et al., 2021; O'Reilly, 1986).

5. Conclusion

In this article we propose a new typology of hikers' pauses in a mountainous area thanks to an original approach in the realm of outdoor recreation studies benefiting from GPS trackers methodology. This typology is composed of breath-taking pauses and eye-catching pauses and is based on temporal characteristics (duration) and geographical characteristics (landscape view, relief, slope). Pauses are taken differently depending on the social characteristics of hikers. Gender, frequency of hiking, age and number of persons inside a group have variable effects on the number and the duration of certain types of pauses. Among those effects, one effect is that largest groups take more pauses and have in total a longer pauses duration than single individuals. Those variable effects illustrate the coupling and the capacity constraints from the time-geography conceptual framework.

While our proposed pause typology is new, we also call for new further approaches to better understand the roles of pauses in individuals' experience of their hike in nature (Lehnen et al., 2022; Nisbet, Zelenski, & et Steven, 2009). A coupling of questionnaires with interviews, or post-hike semantic enrichment of pauses by the hikers themselves would appear as a fruitful way to delve into how hikers perceive the role of pauses and whether they have positive or negative impacts on how satisfied they are with their hike. Possibly, how pauses are perceived by different hikers belonging to the same party could influence the group interactions and individual's fulfillment (sharing the same landscape together) or frustration (if some have to wait for others) (Chai-Allah, 2023). Our classification of pauses should help further studies focusing on the social dynamics and satisfaction of recreationists.

Another insight of this article is the detection and quantification of frequentation hotspots in the studied area, beyond the "obvious" hotspots located at breathtaking places. This provides key-information for outdoor recreation stakeholders to decide on measures to mitigate recreationists' impacts on wildlife and natural environments (Thel, 2023-a).

CRediT authorship contribution statement

Colin Kerouanton: Conceptualization, Data curation, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Laurence Jolivet:** Conceptualization, Supervision, Writing – review & editing. **Clémence Perrin-Malterre:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing, Project administration. **Anne Loison:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1

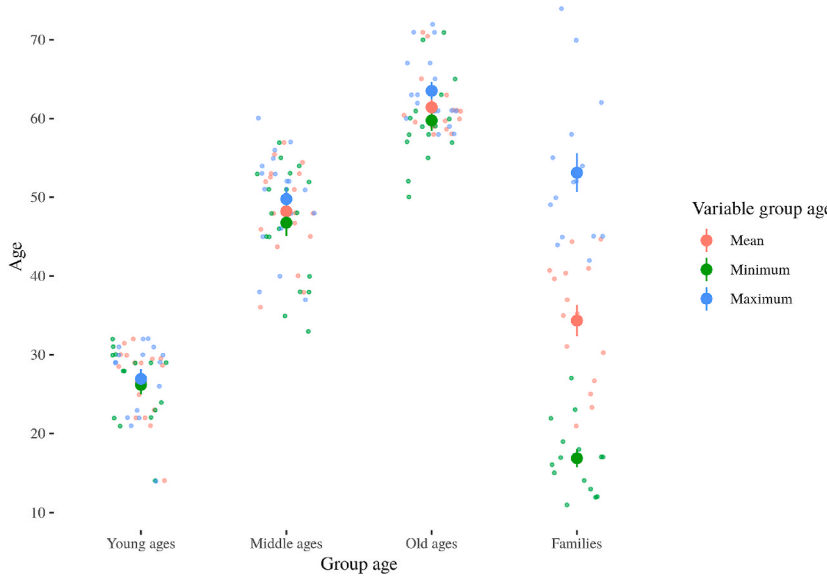

Fig. 5.1. Categories of age defined based on the ages of the group of hikers where one carried the GPS-tracker

Appendix 2

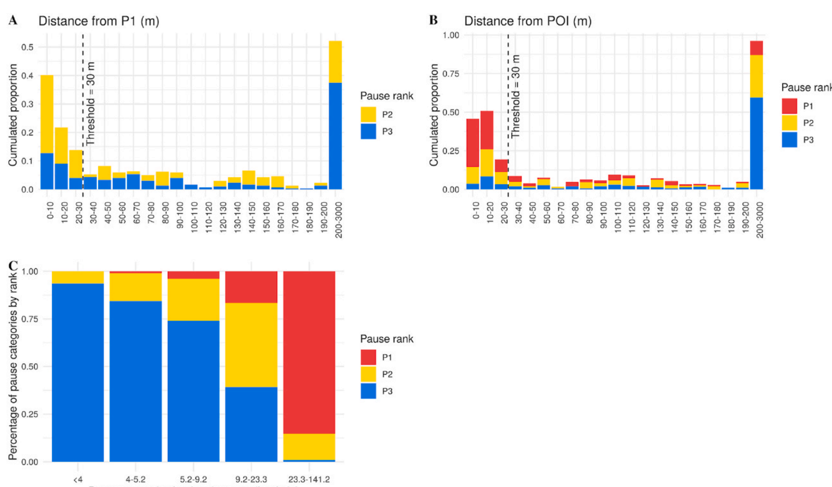

Fig. 5.2. A. Distributions of distances to the closest P1, for P2 and P3 pauses. The threshold value chosen to determine whether a pause was close or far away from P1 was 30 m. B. Distributions of distances between a pause and a Point of Interest (POI) defined as a summit, pass, or mountain refuge. P1 are in grey, P2 in orange and P3 in green. The threshold used in the analyses was 30 m. C. Classification of pauses categories proposed in our ms (P1, P2, P3, based on within-trajectory ranking) in the 5 quantiles of pause duration estimated from the whole pause data set.

Appendix 3

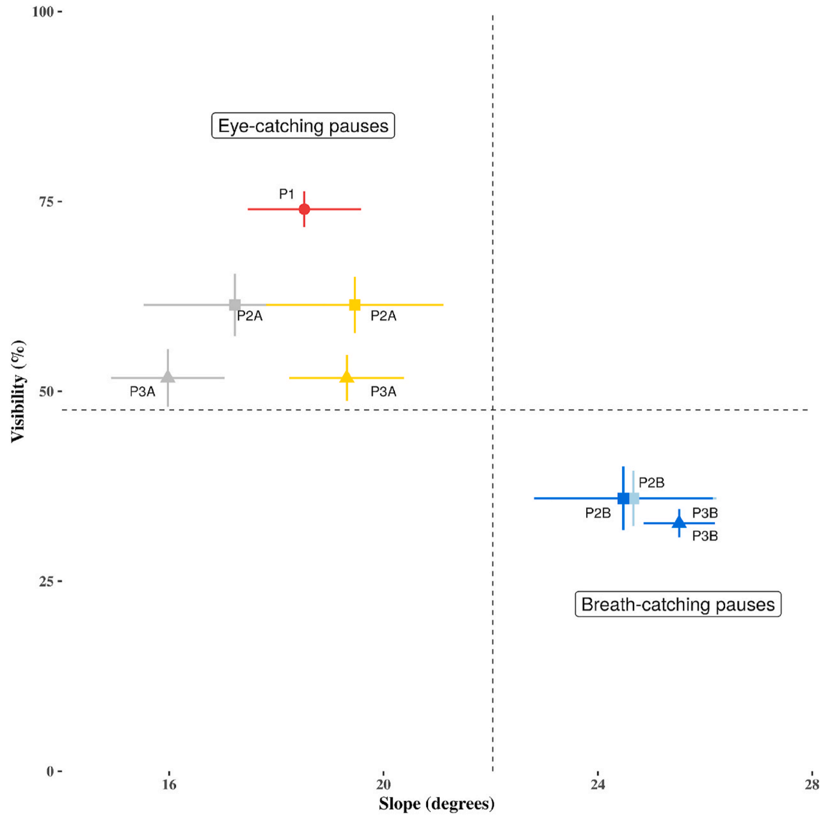

Fig. 5.3. Same as Fig. 4A from main text (mean visibility versus mean slope for pauses of the different categories, P1: circle, P2A: squares in grey or yellow, P2B: squares with light or dark blue, P3A: triangle with grey or yellow, P3B: triangle in light or dark blue), but with different threshold value to distinguish P2A from P2B and P3B, from P3B. In grey and light blue: threshold of 20 m. In yellow and dark blue: with a threshold value of 50 m.

Appendix 4

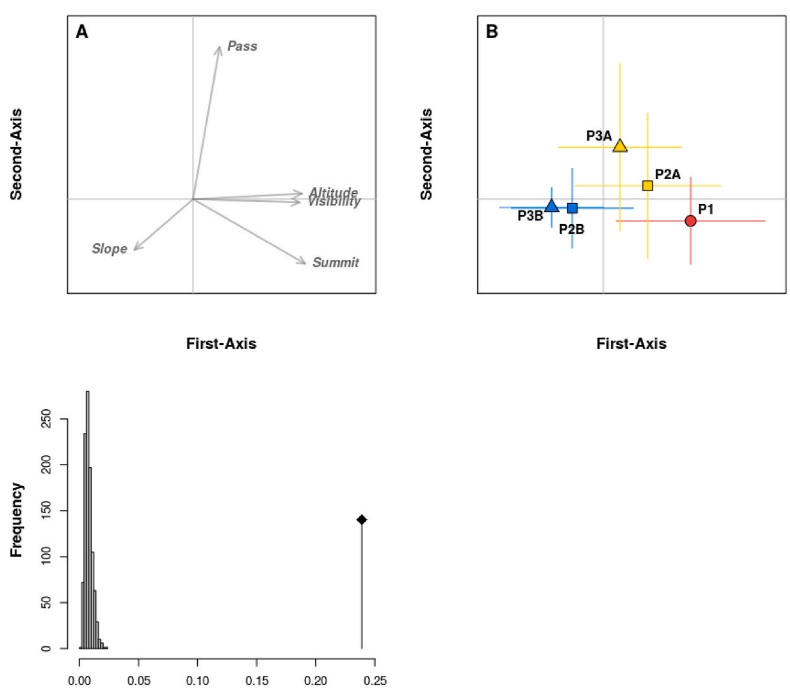

Fig. 5.4. Between-Principal Component Analyses (bPCA) of all pauses by pause category, according to 5 environmental variables: Slope, Visibility, Altitude, Proximity to a summit (Summit), and Proximity to a pass (Pass). A. Positions of the variables. B. Average values and standard deviation of bPCA scores on the 2 first axes per pause category. C. Histogram of the 999 simulated values of the randomization test of the bPCA. The observed value is given by the vertical line, at the right

of the histogram. Given its position far away from the histogram of simulated values, we concluded the categories of pauses differed significantly one from another ($P < 0.01$).

Appendix 5

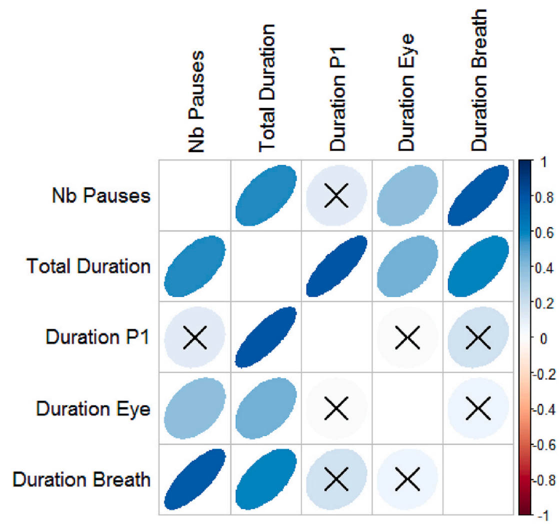

Fig. 5.5. Correlation plot among variables (number of pauses: "Nb Pauses", Total time spent in pause: "Total Duration"; Duration of P1: "Duration P1"; Duration of eye catching pauses: "Duration Eye"; Duration of breath catching pauses: "Duration Breath"). The intensity of the ellipse colour indicate the value of the Pearson correlation coefficient (scale on the right, blue for positive correlation, red for negative correlation). A cross is added where the correlation is non significant ($P < 0.05$).

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