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1 ABSTRACT

Background:

Escalators are used in shopping centres, airports, and train stations, yet their use is not without risk as injuries, even fatalities, can occur during use. This research takes a Human Factors approach to: 1) produce a new Human Factors Incident Taxonomy for Members of the Public (HFIT-MP); and 2) apply the taxonomy to a dataset of serious escalator incidents to explore relationships between the factors and gain insights into escalator incidents.

Methods:

The HFIT-MP was developed using a combination of Human Factors literature, Health and Safety Executive (HSE) guidance, and subject matter experts. Narrative escalator incident reports spanning 31st January 2015 to 31st January 2016 were obtained from HSE and coded according to the HFIT-MP. Inter-rater agreement was measured using Cohen's Kappa for a sample of incidents. The full incident dataset was investigated using frequency distributions and Multiple Correspondence Analysis (MCA) coupled with cluster analysis to identify factors that tended to occur together.

Results:

The final HFIT-MP consisted of four overarching themes and 25 factors. Double coding of 197 of the 403 escalator incidents using the HFIT-MP demonstrated substantial to almost perfect levels of agreement (all factors achieved Kappa > 0.60). Analysis of all 403 escalator injury reports indicated that 93% were falls. MCA identified six groups of factors that tended to occur together; for example, falls occurred more frequently with those 65 or over, those who lost footing, getting onto the escalator, not making any unexpected movements, the escalator descending, and travelling alone.

Conclusion:

Results provide health and safety practitioners with possible target groups (e.g., age), actions (e.g., getting onto the escalator) and locations (e.g., descending escalator) to inform interventions. Results also support the need to consider the interaction of multiple factors among incidents involving members of the public. Further application of the HFIT-MP to different sources and modes of data, such as video footage, could further refine the HFIT-MP.

Keywords: Human Factors, Falls, Escalator Incidents, Incident, Taxonomy

2 INTRODUCTION

Escalators are commonly found in most shopping centres, train stations, and airports and used by people to move through these environments (Howland, Bibi, English, Dyer, & Peterson, 2012; Lee et al., 2010). However, their usage is not without some risk; a review of US Consumer Product Safety Commission (CPSC) data by McCann (2013) identified 39 escalator related deaths over a 13-year period between 1997 and 2010. Moreover, US Hospital admissions data indicates that there are 2,500 – 6,000 non-fatal escalator incidents reported annually, 75.0% - 84.9% of these incidents are falls, and 3% - 20% are due to entrapments (McCann, 2013; O'Neil et al., 2008). By comparison, in Great Britain (GB) detailed escalator incident research is limited. By way of example, a research report (Page & Hough, 1989), was produced 30 years ago by the Health and Safety Executive (HSE), the main regulator for health and safety legislation. Although there is no current central repository of escalator incidents in GB, any incident which involves a member of the public within a workplace, which is severe enough to necessitate hospital treatment, should be reported to the appropriate enforcing authority through the HSE online portal. Subsequently, severe escalator incidents are recorded in HSE's Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013 (RIDDOR) database (HSE, 2013). The present study will therefore seek to extend current understanding of the factors that contribute to escalator incidents through analysis of the RIDDOR database.

The research examining the causes of escalator-related incidents is limited (Chi et al., 2006; Page & Hough, 1989, Xing et al., 2019). Using an escalator involves a person getting onto and then off a moving surface (Hsu, et al., 2015). During this behaviour, it is likely that several performance influencing factors (PIFs) (HSE, 1999) could contribute to an escalator incident occurring (Al-Sharif, 2006; Basir et al., 2018). To explore the potential PIFs that lead to an incident, the current research adopts a Human Factors approach to produce an investigative taxonomy for escalator incidents involving members of the public. A Human Factors approach focuses on how a human performs an action/task and aims to identify and categorise the PIFs which may influence the outcome of the action/task in a bid to reduce user error and prevent injury (Noyes, 2002; Stanton et al., 2013; Wilson & Corlett, 1995). Previous escalator incident research has adopted a Human Factors approach (Al-Sharif, 2006; Chi et al., 2006),yet their application has been limited as they have not considered a person's age as a PIF (Al-Sharif, 2006) or they have not considered that there may be multiple PIFs that lead to an incident occuring (Chi et al., 2006; Xing et al., 2019).

There are several investigative Human Factors taxonomies available to incident investigators (Stanton, Salmon & Rafferty, 2013). However, extant taxonomies have been built around the premise of there being a conventional organisational structure (HSE, 1999; Kyriakidis et al., 2018). Such taxonomy design does not adequately capture how members of the public may behave when using an escalator, as they are not required to be trained, supervised, or adhere to specific procedures as outlined by an organisation. Further, existing taxonomies can be over complex (O'Connor & Walker, 2011) and require specialist knowledge to understand the terminology being used, meaning that application outside of a specialist setting could be limited.

In summary, research investigating the potential causes of escalator incidents is limited, with extant literature (Chi et al., 2006; Xing et al., 2019) focusing on identifying the primary factor(s) that may lead to an incident and not any potential combinations of these factors. Human Factors approaches have been proposed to offer a method with which to explore escalator incidents, but existing taxonomies (Wiegmann & Shappell, 2001) are limited as they do not offer sufficient consideration of how to investigate incidents, which solely involve a member of the public. In order to the address these gaps in the literature, the present research has two distinct aims: (i) to develop a new Human Factors taxonomy for the investigation of escalator incidents involving members of the public; and (ii) apply the taxonomy to the HSE RIDDOR dataset of serious escalator incidents in order to explore relationships between the factors of the taxonomy and gain insights into escalator incidents.

3 METHOD

3.1 PARTICIPANTS

A retrospective review was conducted on all recorded escalator incidents (i.e., events that were identified using the keyword “escalator”), that had been reported to HSE between 31st January 2015 and 31st January 2016 and held in their RIDDOR database. All records were anonymised before being provided to the researchers. Each incident report included the date, age, and sex of the injured person, and a short description of the incident. The level of detail in each report varied as some only provided a brief narrative and the injured person’s sex. All returned incidents (*N* = 439) were reviewed and cases that were deemed to be outside the scope of the study (i.e., involved an incident near an escalator but not involving use of the escalator) were removed, as were any duplicated reports. Subsequently, a sample of 403 non-fatal, serious escalator-related incidents, taken from 154 Local Authorities (LA) were analysed as part of this study. The study received approval from the University of Portsmouth ethics committee [SFEC: 0491-9C9F-3B86-C01E-FAEB-A9E2-A73E-77CB].

PROCEDURE

3.1.1 Development of the Human Factors Incident Taxonomy for Members of the Public (HFIT-MP)

Reviewing incident reports and extant literature have been adopted in the development of incident taxonomies across domains, including shipping incidents (Chauvin et al., 2013), crane incidents (Shepherd, Kahler, & Cross, 2000), medical incidents (Mitchell et al., 2015), and amusement park ride incidents (Woodcock, 2008). Therefore, this study took a similar approach by using academic literature, but extended it by using both expert knowledge and HSE’s investigative taxonomy (HSE, 1999). Subsequently, the lead author produced the outline for the taxonomy integrating: (i) findings from current escalator injury research (Al-Sharif, 2006; Chi et al., O’Neil et al., 2008); (ii) falls literature regarding stairway negotiation (Jacobs, 2016), and risk factors associated with falls (Hamacher et al., 2011); (iii) expert knowledge from an HSE Senior Ergonomics and Human Factors Specialist (LY) and an HSE Senior Falls Prevention Specialist (RS); and (iv) two existing Human

Factors taxonomy approaches (HSE's industry guidance (HSE, 1999), and the HFACS (Stanton et al., 2013; Wiegmann & Shappell, 2001). The unique inclusion of HSE specialist knowledge, which drew upon their experiences of investigating health and safety incidents, and their work with organisations outside the Human Factors discipline helped to ensure the terminology used in the taxonomy is understandable, a critique of previous works (Taib et al., 2011).

The taxonomy consisted of four overarching themes: (1) *Individual factors* such a person's age or sex; (2) *Task factors* relating to how an escalator user may have been behaving at the time that they were injured, such as getting on or off the escalator or not holding the handrail; (3) *Environmental factors* relating to the escalator such as whether the escalator was ascending or descending, or whether the escalator was operating correctly; and (4) *Outcome factors*, which reflect the impact of the incident on the person.. Figure 1 shows the factors overlapping; this is intentional as it is likely that while some factors may be independently influential, more typically there will be a combination of factors that lead to an outcome.

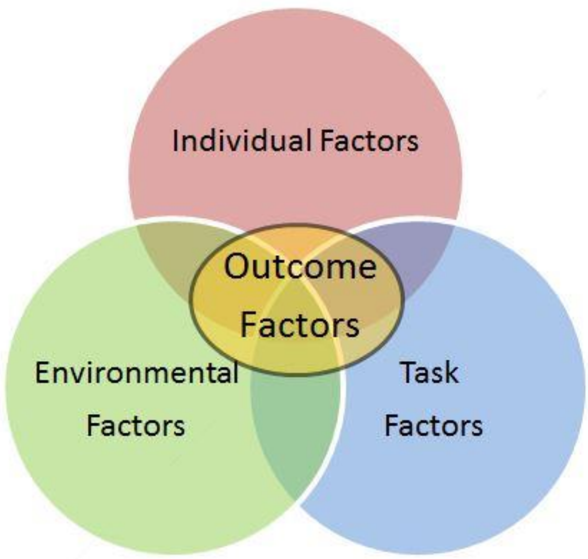

Figure 1: Themes of the proposed taxonomy for escalator incidents

Following the approach of Mitchell et al. (2015) and other taxonomy-led investigations (Olsen & Williamson, 2017), the descriptions of the 403 incidents were reviewed by three researchers (PB, LY, RB) who identified all reported components of an escalator incident, which then became factors under the four themes. A hypothetical example would be if the incident narrative stated: “a lady fell whilst getting onto the ascending escalator”. The components recorded would be that the person’s sex was female (individual factor), she fell (outcome factor), she was getting on to the escalator (task factor) and it was the ascending escalator (environmental factor). Where a person was described as using a walking aid, such as a walking stick, these individuals were coded as having mobility issues. A combined list of all the factors identified by all three researchers across all incident reports was produced. This was reviewed by all three researchers separately, before they discussed the list to come to a consensus. There was disagreement between the researchers regarding the factor’s loss of footing and loss of balance, which were considered as possibly being separate codes for the same factor and used interchangeably in the narrative reports. As literature on escalator injuries is limited, it was agreed the two separate factors remained within the taxonomy. Finally, the lead author re-coded all 403 escalator incidents using the final HFIT-MP to provide the final coded dataset.

DATA ANALYSIS

3.1.2 Inter-rater reliability of the HFIT-MP

Cohen’s Kappa was used to assess the inter-rater reliability of coding escalator incidents according to the final HFIT-MP (McHugh, 2012). An independent coder who had not been involved in the development of the taxonomy coded approximately half (N = 197) of the escalator incident reports. This coding was then compared to the final coded dataset produced by the lead researcher. A sample size of 197 would achieve a 95% confidence interval with a width of .279 if the value of Kappa was 0.5 (i.e., moderate agreement) and a width of 0.168 if the value of Kappa was 0.7 or 0.9 (i.e., substantial or almost perfect agreement), assuming that the proportion of incidents classified identically by both coders was 0.8 (PASS 2020).

3.1.3 Exploratory Analysis of Factors among Escalator Incidents

The occurrence of factors among escalator incidents was summarised using frequency distributions. Multiple Correspondence Analyses (MCA) (Panagiotakos & Pitsavos, 2004) was used to explore the positive relationships across the factors of the HFIT-MP and has been used in previous Human Factors incident investigations (Chauvin et al., 2013). Factors were screened for inclusion into the MCA using Fisher's Exact test for all pairwise comparisons. *P*-values were adjusted for multiple comparisons using Bonferroni correction. Only those factors that had a statistically significant association (at adjusted $p<0.05$) with at least one other factor were included in the MCA, which helps restrict noise in the MCA and is similar to the approach used by Ginis et al. (2010) to facilitate interpretation.

To determine the number of dimensions for the MCA, the total inertia (variance) for each dimension was examined with dimensions accounting for 10% or more of the variance retained. To aid interpretation of the results, agglomerative hierarchical cluster analysis was used on the dimensional coordinates of the factor categories to group them together (Costantino et al., 2016). Complete-linkage cluster analysis was used because this leads to less chaining than other methods (Mamun, Aseltine, & Rajasekaran, 2016). The results are presented in a dendrogram and the Duda-Hart Index was consulted to help decide how many groups should be created (Everitt & Rabe-Hesketh, 2006). The strength of association for factor categories within the same group was assessed using the Euclidean distance between the origin and the centroid of the group. This was turned into a score from 1 (weakest association) to 4 (strongest association) by scaling the Euclidean distance. All statistical analyses were undertaken using Stata V16.0 statistical software.

4 RESULTS

4.1 HUMAN FACTORS INCIDENT TAXONOMY FOR MEMBERS OF THE PUBLIC (HFIT-MP)

There were 25 factors included in the final HFIT-MP (see Figure 2). Twenty three of the factors include an 'unknown' category, with 12 instances of factors having just a 'yes' and 'unknown' option. The inclusion of 'unknown' was deliberate to highlight that the incident reports did not contain all of the information needed to accurately code all factors, and to avoid forcing the coder to make assumptions about the incident. Whilst most are self-explanatory, 'unexpected movement' requires further clarification. A passenger moves when stepping onto or off the moving escalator steps and so this is expected movement. However, they should not be moving (i.e. reaching for a falling item) or walking once boarded as escalators are not intended to be used as a staircase (BS EN 115-1:2017 (British Standards Institute, 2017)) and so this would be unexpected movement.

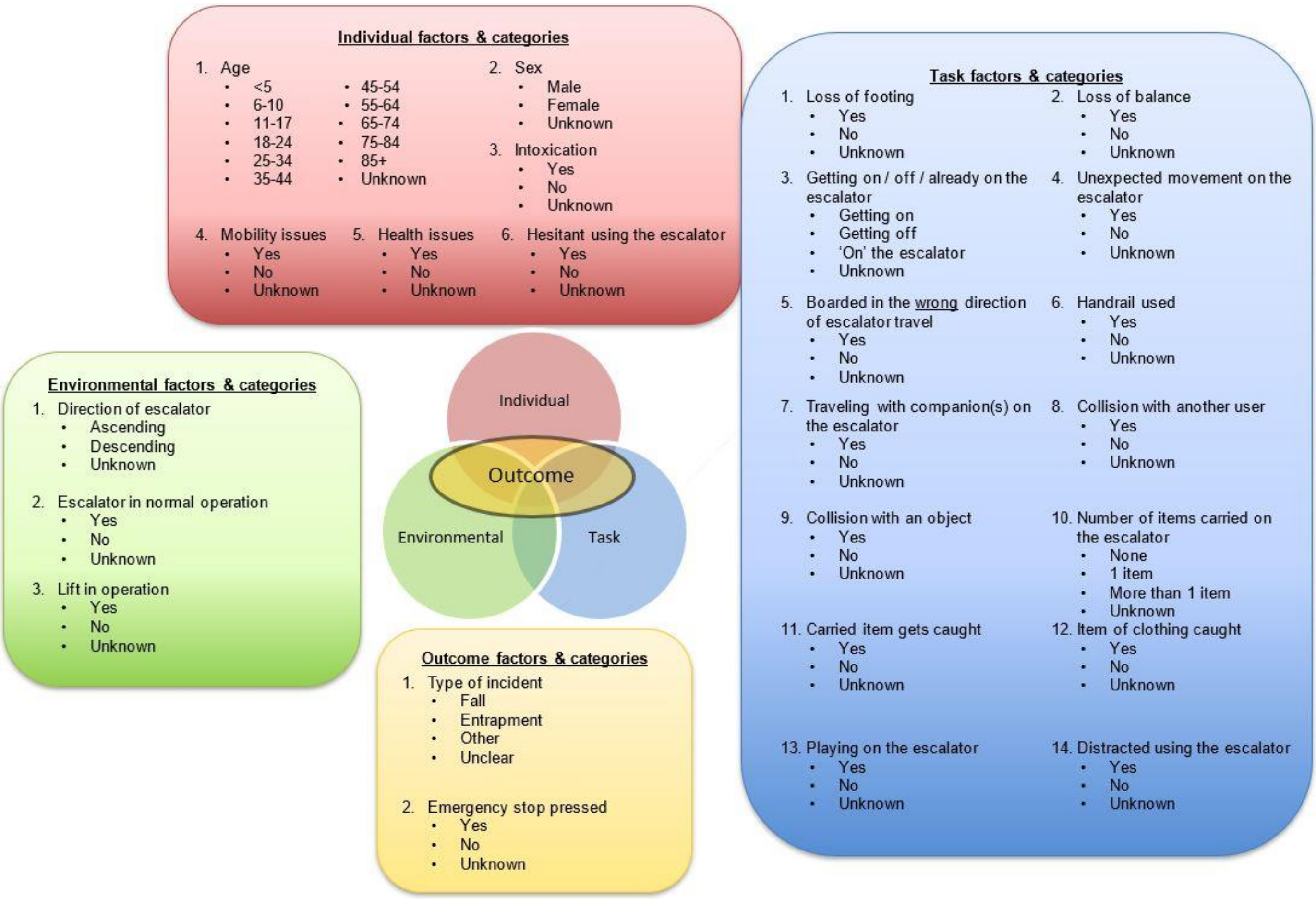

Figure 2: Human Factors Incident Taxonomy for Member of the Public (HFIT-MP) for escalator incidents. Included are the four top-level themes of the taxonomy and the corresponding factors that are within each theme.

4.2 INTER-RATER RELIABILITY

Table 1 shows the percentage agreement between the two coders and the estimated Cohen's Kappa. All 23 factors (where Kappa could be estimated) had a Kappa of 0.60 or above, indicating substantial agreement between coders; although some confidence intervals were wide (e.g. distracted using the escalator). Ten factors had a Kappa of at least 0.80, indicating almost perfect agreement between coders for these factors.

Table 1 Inter-rater reliability of the MFIT-MP factors based on 197 escalator incidents

Theme	Factor	% agreement	Cohen's Kappa	95% confidence interval	
				Lower limit	Upper limit [b]
Outcome factors	1. Type of incident	95.4%	0.739	0.631	0.846
	2. Emergency stop pressed	90.9%	0.621	0.496	0.746
Individual factors	1. Age	NA	NA	NA	NA
	2. Sex	NA	NA	NA	NA
	3. Intoxication	99.5%	0.931	0.791	1.070
	4. Mobility issues	95.9%	0.851	0.712	0.990
	5. Health issues	93.9%	0.717	0.583	0.851
	6. Hesitant using the escalator	99.5%	0.798	0.661	0.934
Task factors	1. Loss of footing	91.9%	0.776	0.640	0.911
	2. Loss of balance	85.3%	0.685	0.552	0.818
	3. Getting on / off / already on escalator	84.3%	0.779	0.693	0.865
	4. Movement beyond that expected	83.2%	0.658	0.558	0.758
	5. Boarded in the wrong [b] direction of escalator travel	99.5%	0.798	0.661	0.934
	6. Handrail used	97.0%	0.780	0.664	0.896
	7. Traveling with companion(s) on the escalator	95.4%			
	8. Collision with another user		0.888	0.760	1.016
	9. Collision with an object	98.5%	0.872	0.732	1.011
	10. Number of items carried on the escalator	99.0%	0.795	0.658	0.932
	11. Carried item gets caught	95.9%	0.899	0.784	1.014
	12. Item of clothing caught	97.0%	0.757	0.644	0.870
	13. Playing on the escalator	99.5%	0.886	0.748	1.025
	14. Distracted using the escalator	99.5%	0.798	0.661	0.934
Environmental factors	1. Direction of escalator	95.9%	0.618	0.489	0.747

	2. Escalator in normal operation	90.9%	0.856	0.754	0.957
	3. Lift in operation	92.9%	0.849	0.725	0.974

NA: this information was provided as part of the incident report form.
a, boarding in this instance can refer to any action by which a person gets onto the escalator (i.e. step, run, jump).
b, due to the method of estimation, the upper limit of the 95% confidence can be greater than one (the maximum possible value of Kappa).

4.3 DESCRIPTIVE DATA

4.3.1 Outcome Factors

The results indicated that 93.0% (*N* = 375) of the 403 incidents reviewed were the result of a fall and 5.0% were due to an entrapment. In 2.0% of the incidents the outcome was not clear. The results indicated that in 11.2% (*N* = 45) of cases the emergency stop button was pressed. A full breakdown is presented in Table 2.

Table 2 Frequency distributions for Outcome Factors among 403 escalator incidents

Factor	Category	Frequency	Percentage
1. Type of incident	Fall	375	93.0%
	Entrapment	20	5.0%
	Other	0	0.0%
	Unclear	8	2.0%
2. Emergency stop pressed	Yes	45	11.2%
	No	6	1.5%
	Unknown	352	87.3%

4.3.2 Individual Factors

The mean age of the people involved in a reported incident was 65.8 years (*SD* = 28.2). Age was missing from 24.3% of incident reports. Excluding the unknown age category, the modal age category was 75-84 years (23.3%). Sex was always provided on the reports; 37.2% were male (*N* = 150), and 62.8% were female (*N* = 253). Of the other factors in this theme, mobility issues were the most frequently reported (15.4%) and hesitancy the least reported (1.7%). A full breakdown is presented in Table 3.

Table 3 Frequency distributions for Individual Factors among 403 escalator incidents

Factor	Category	Frequency	Percentage
1. Age	< 5	27	6.7%
	6 – 10	9	2.2%
	11 – 17	5	1.2%
	18 – 24	8	2.0%
	25 – 34	6	1.5%
	35 – 44	2	0.5%
	45 – 54	9	2.2%
	55 – 64	17	4.2%
	65 – 74	46	11.4%
	75 – 84	94	23.3%
	85 +	82	20.4%
	Unknown	98	24.3%
2. Sex	Male	150	37.2%
	Female	253	62.8%
	Unknown	0	0.0%
3. Intoxication	Yes	11	2.7%
	No	0	0.0%
	Unknown	392	97.3%
4. Mobility issues	Yes	62	15.4%
	No	0	0.0%
	Unknown	341	84.6%
5. Health issues	Yes	35	8.7%
	No	0	0.0%
	Unknown	368	91.3%
6. Hesitant using the escalator	Yes	7	1.7%
	No	0	0.0%
	Unknown	396	98.3%

4.3.3 Task Factors

The most frequently reported Task factor categories were: getting on the escalator (36.5%, *N* = 147); loss of balance (34.0%, *N* = 137); the person not moving more than expected when using an escalator (34.0%, *N* = 137); loss of footing (28.5%, *N* = 115); and travelling with a companion (25.3%, *N* = 102). Boarding the escalator in the wrong direction and playing on the escalator were rarely reported (1.5% and 1.7% respectively). A full breakdown is presented in Table 4.

Table 4 Frequency distributions for Task Factors among 403 escalator incidents.

Factors	Category	Frequency	Percentages
1. Loss of footing	Yes	115	28.5%
	No	0	0.0%

Factors	Category	Frequency	Percentages
	Unknown	288	71.5%
2. Loss of balance	Yes	137	34.0%
	No	0	0.0%
	Unknown	266	66.0%
3. Getting on / off / already on the escalator	Getting on	147	36.5%
	Getting off	37	9.2%
	'On' the escalator	122	30.3%
	Unknown	97	24.0%
4. Unexpected movement on the escalator	Yes	55	13.7 %
	No	137	34.0%
	Unknown	211	52.4%
5. Boarded in the wrong direction of escalator travel	Yes	6	1.5%
	No	0	0.0%
	Unknown	397	98.5%
6. Handrail used	Yes	26	6.5%
	No	9	2.2%
	Unknown	368	91.3%
7. Traveling with companion(s) on escalator	Yes	102	25.3%
	No	2	0.5%
	Unknown	299	74.2%
8. Collision with another user	Yes	33	8.2%
	No	0	0.0%
	Unknown	370	91.8%
9. Collision with an object	Yes	11	2.7%
	No	0	0.0%
	Unknown	392	97.3%
10. Number of Items carried on escalator	None	0	0.0%
	1 item	79	19.6%
	More than 1 item	24	6.0%
	Unknown	300	74.4%
11. Carried item gets caught	Yes	15	3.7%
	No	11	2.7%
	Unknown	377	93.6%
12. Item of clothing caught	Yes	10	2.5%
	No	0	0.0%
	Unknown	393	97.5%
13. Playing on the escalator	Yes	7	1.7%
	No	0	0.0%
	Unknown	396	98.3%
14. Distracted using the escalator	Yes	22	5.5%
	No	0	0.0%
	Unknown	381	94.5%

4.3.4 Environmental Factors

The most frequently reported Environmental factor categories were: people using the ascending escalator (42.4%, *N* = 171) and the escalator functioning normally at the time of the incident (27.1%, *N* = 109). The operational status of any nearby lift was rarely reported (2.0%). A full breakdown is presented in Table 5.

Table 5 Frequency distributions for Environmental Factors among 403 escalator incidents.

Factors	Category	Frequency	Percentages
1. Direction of escalator	Ascending	171	42.4%
	Descending	83	20.6%
	Unknown	149	37.0%
2. Escalator in normal operation	Yes	109	27.0%
	No	18	4.5%
	Unknown	276	68.5%
3. Lift in operation	Yes	0	0.0%
	No	8	2.0%
	Unknown	395	98.0%

4.4 MULTIPLE CORRESPONDENCE ANALYSIS AND HIERARCHICAL CLUSTERING

Twelve of the 25 factors had a statistically significant association with at least one other factor during the pairwise screening process. These factors were included in the MCA. The scree plot from the MCA showed a drop in the principal inertias after the first four dimensions (Figure 5, Appendix A). The first dimension accounted for 21.3% of the total inertia (variance), the second dimension accounted for 17.9%, and the third for 12.9%. Each dimension after that accounted for less than 10% of the total inertia. The first three dimensions were therefore retained for use in the hierarchical cluster analysis. To identify the best group solution, the Duda-Hart Index was inspected. An eight-group solution had one of the highest Je(2)/Je(1) values and a low pseudo-T-squared value followed by an increase in the pseudo-T-squared value (Everitt & Rabe-Hesketh, 2006) (Figure 3b, Appendix B), suggesting this was a reasonable number of groups. The resulting dendrogram from the hierarchical cluster analysis showing the dissimilarity cut-off for the eight-group solution is shown in Figure 3.

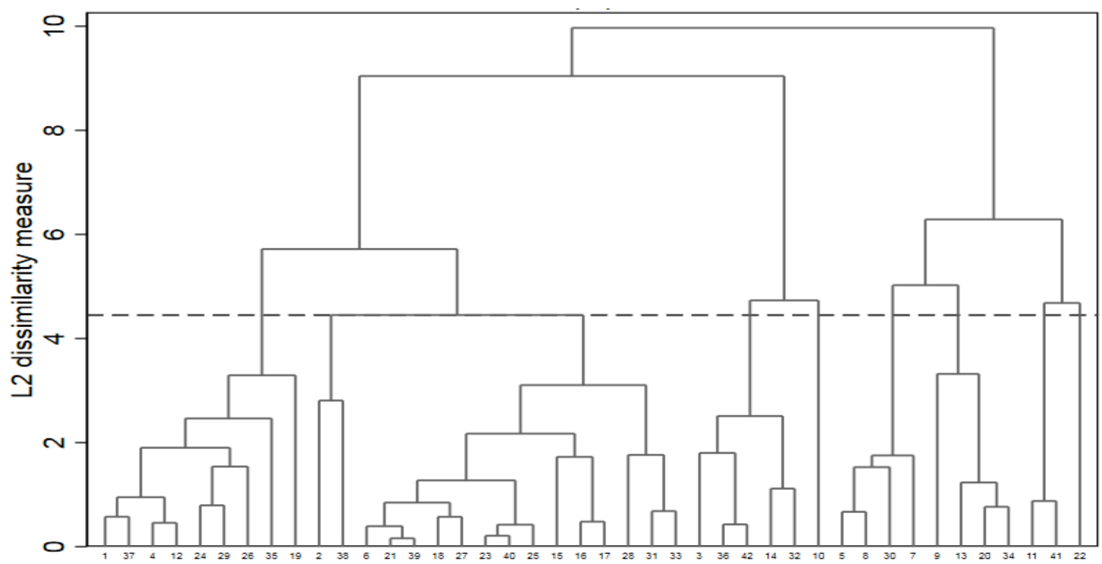

Figure 3 Dendrogram for the hierarchical cluster analysis of the three-dimensional category coordinates showing the dissimilarity cut-off for the eight-group solution (dashed line)

Figure 4 shows the final category groupings based on MCA and cluster analysis, ordered according to the strength of association between categories within the same group. To facilitate interpretation, the ‘unknown’ categories for all factors have been condensed (a full breakdown is in Appendix C). Two factor categories were placed in groups on their own by the cluster analysis (i.e., no other factor categories were in their groups), and have been labelled as outliers in Figure 4.

Group 7 (Strength of association 4) reflects the factor categories with the strongest associations; in this case, age 25-34 and entrapment, which suggests that these categories occurred frequently together in the incident reports. The results indicated that incidents reporting a fall also frequently reported that the individual was over 65 years of age, getting onto the escalator, the individual had lost their footing, there was no unexpected movement on the escalator, they were not travelling with companions, and the escalator was descending (Group 2, Strength of association 1; Figure 4). The outcome factor category of ‘unclear’ incidents (i.e., those where the type was not clear) occurred relatively frequently with the age category of 55-64 years (Group 3, Strength of association 2; Figure 4).

The remaining groups did not contain a category from the ‘type of injury’ factor. Group 6 (Strength of association 3) suggested that the factor categories of age 11-17 or 45-54, getting off an escalator, and the emergency stop being pressed were frequently reported together. The factor categories of age 10 or under, unexpected movement when using the escalator, and the escalator not operating normally, occurred more frequently together (Group 5; Strength of association 2, Figure 4). Finally, the factor categories of age 35-44, loss of balance, “on” the escalator (as opposed to getting on or off), traveling with companions, colliding with another user, the escalator ascending, the escalator operating normally, and the emergency stop being pressed occurred frequently together (Group 1; Strength of association 1, Figure 4).

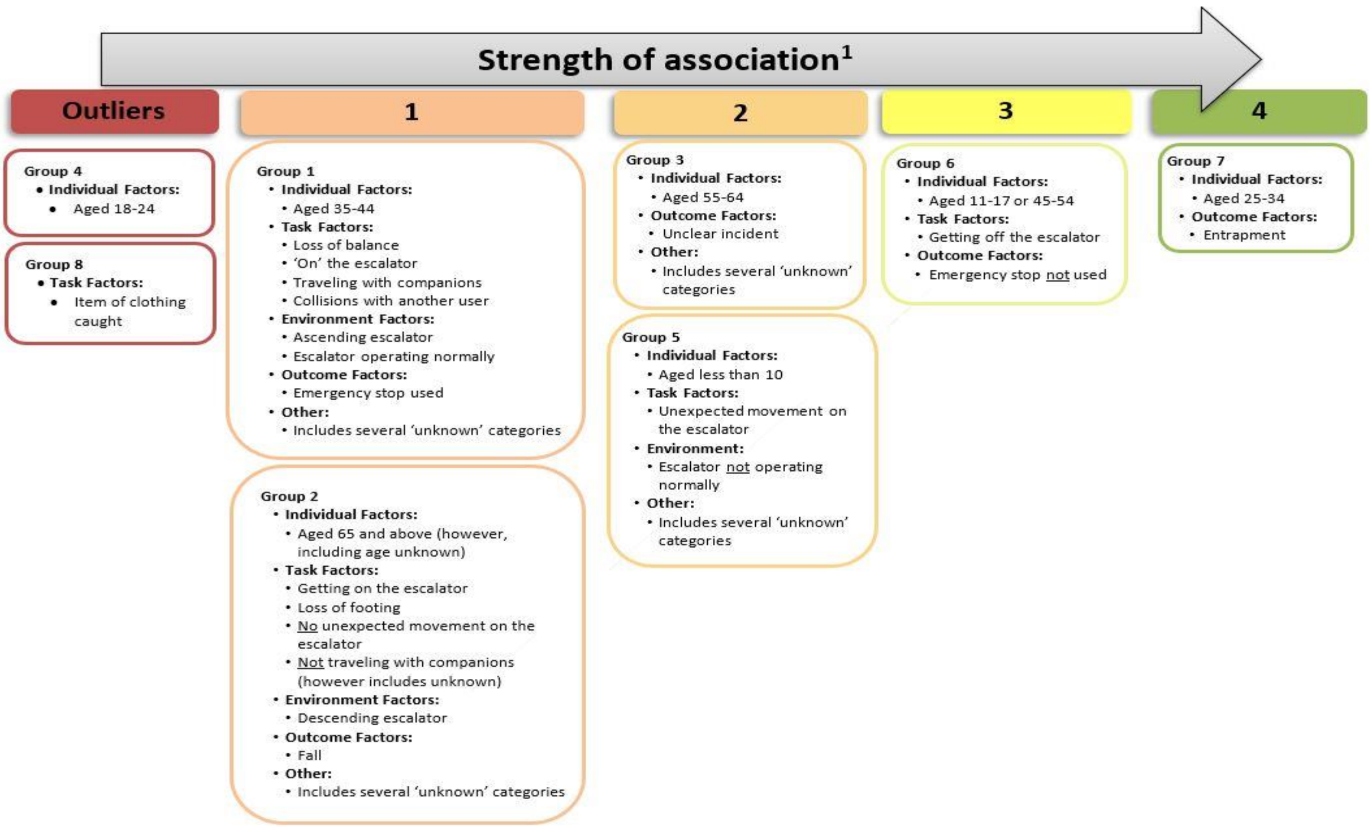

Figure 4 Groupings of factor categories based on Multiple Correspondence Analysis followed by cluster analysis. Ordered by strength of association between categories in the same group.
[1], based on Euclidean distance of group centroid from origin: 1 = weakest association, 4 = strongest association between categories

5 DISCUSSION

Despite research evidence demonstrating that escalator-related incidents can result in fatalities (McCann, 2013), investigation of the potential causes is limited, with extant literature (Chi et al., 2006; Xing et al., 2019) only focusing on identifying the primary factor(s) that may lead to an incident and not the potential combinations of these factors. The aims of this research were to: 1) develop a new Human Factors taxonomy for the investigation of escalator incidents involving members of the public; and 2) to apply the taxonomy to the HSE RIDDOR dataset of serious escalator incidents in order to reveal relationships between the factors of the taxonomy, and subsequently gain new understanding into the factors that contribute towards escalator incidents. The following discussion is split into two sections, first evaluating the HFIT-MP in respect of its design and second, the applicability of the HFIT-MP to escalator incidents.

5.1 DEVELOPMENT OF THE HFIT-MP

This study has developed a new taxonomy that enables reliable coding of escalator incidents to help researchers identify performance influence factors (PIFs). In line with previous incident taxonomy approaches (Shepherd, Kahler, & Cross, 2000; Chauvin et al., 2013), four key themes were established as a basis for the HFIT-MP: individual, task, environment, and outcome. Yet, unlike previous approaches the HFIT-MP was designed to accommodate the behaviours of members of the public, which are not constrained by conventional organisational structures that previous taxonomies have been designed around (e.g., the Human Factors Analysis and Classification System, HFACS (Wiegmann & Shappell, 2001)). Further, the HFIT-MP was designed in an ‘open’ manner (i.e., four top level themes as opposed to specifics) in order to ensure that factors relevant to an escalator incident were not inadvertently missed (Baysari et al., 2009; Salmon et al., 2012), and to enable prospective researchers to make adaptations to fit the taxonomy due to a limited level of information available in incident reports (Mitchell et al., 2015).

The HFIT-MP was refined using escalator incidents that were serious enough to have been reported to the HSE and as such will have necessitated hospital treatment for the injured person. Despite this, there were several factors that had minimal responses within escalator incident reports. For example, in 74% of incidents, it was unknown whether a person was traveling with a companion or not. The large proportion of 'unknowns' in the dataset demonstrated the inconsistent and incomplete nature of narrative reporting of incidents (Davies et al., 2007; Rossignol, 2015; Woodcock; 2008). The current results therefore reinforce the need for a uniform way of reporting not only escalator incidents but incidents more generally (Rossignol, 2015), in order to adequately identify common factors, which may facilitate the development interventions to reduce incidents from occurring. The HFIT-MP could form the basis of such a reporting system and extend to other incidents involving members of the public such as stair way falls (e.g., Jacobs, 2016). Moreover, low frequency factors were included within the HFIT-MP due to the fact that, although infrequent, they may be underrepresented in the current dataset or may contribute to an incident when considered in combination with other factors (Reason, 1990).

There is potential for bias to be introduced during the development of any taxonomy (Mays & Pope, 1995). To ensure rigour and in order to keep biases to a minimum, the taxonomy was developed through a triangulation of various sources such as academic literature (e.g., Wiegmann & Shappell, 2001), HSE guidance (HSE, 1999) and subject experts in ergonomics, human factors and falls prevention. Further the dataset analysed was not limited to one specific organisation but comprised data collected from 154 local authorities across GB, highlighting that the taxonomy and associated findings are likely to be generalisable to the wider population of escalator incidents. Further the results of the inter-rater agreement analysis highlighted a good degree of consistency between two coders with factors having substantial to almost perfect levels of agreement. To improve these scores further additional training or a specific training course could be provided for users to practice implementing the taxonomy (Goodell et al., 2016).

5.2 APPLICATION OF THE HFIT-MP

MCA followed by hierarchical cluster analysis were used to identify and then explore the relationships between factors involved in serious escalator incidents. Comparable to escalator incident research in Taiwan, Hong Kong, the US, China and GB (Chi et al., 2006; Lee at al., 2010; Howland et al., 2012; O'Neil et al., 2008; Xing et al. 2019; Page & Hough, 1989) the results demonstrated that most incidents in the HSE dataset resulted from a person falling whilst using the escalator (93%) with entrapment incidents being the second most frequent (5%). This finding suggests a potential uniformity regarding the most prevalent type of escalator incidents, irrespective of geographical location. As falls were the most frequently recorded outcome, this incident occurred together with many other factors, but with relatively weak associations (compared to other groups identified). Specifically, the MCA indicated that fall incidents were frequently reported together with factors including the individual being aged 65 years or older, getting onto the escalator, the escalator being a descending direction of travel, the individual was not moving (i.e., they stepped onto the escalator then remained stationary), and traveling alone and lost their balance (i.e., a stumble, misstep). Explanation for this particular combination of factors can be discerned from literature demonstrating that an older person's perceptual-motor control can be compromised by a combination of: reduced mobility due to age-related physiological changes (Kenny et al., 2017), the disorientation experienced when using descending escalators (Cohn & Lasley, 1990), and the complex demand of stepping onto a moving surface (Hsu et al., 2015). Declines in perceptual-motor control associated with ageing may lead to a loss of foot placement accuracy (Roerdink et al., 2021) or loss of balance (Zhang et al., 2020), ultimately leading to a fall. Interventions that aim to reduce escalator falls may target older adult populations that appear to reflect the most at risk demographic (Hoogendijk et al., 2019). Such an intervention could look to reduce the burden on an older person stepping onto a moving surface, perhaps using different markings on escalator steps (Jacobs, 2016) or changes to the speed of the moving surface (Hsu et al., 2015).

Entrapments accounted for just 5% of incidents and the MCA suggested that they were frequently reported together with adults aged 25 - 34. Whilst the low percentage of entrapment injuries is consistent with extant literature (Chi et al., 2006; Lee et al., 2010), previous findings suggested that children under the age of 5 age most frequently encountered entrapment injuries. In the current study, the strong association between adults aged 25 - 34 and entrapments were not frequently associated with other factors, most likely due to the fact that the number of entrapments in the current dataset were too few or they were more strongly related to other factors and so appeared in different groupings in the MCA. Conversely, it could be that there are additional influential factors not currently included in the HFIT-MP such as risk-taking behaviour amongst younger persons resulting in behaviours that lead to entrapments (Albert, et al., 2013). Future research could focus on identifying individual attitudes and perceptions to the risks associated with escalator use to better understand this finding.

The MCA also identified other factor combinations that tended to occur together in escalator incident reports; although they did not have an affiliation with a particular incident type (i.e., a fall or entrapment). These relationships offer useful insights into patterns of incidents for health and safety professionals. For example, one group included the factors of individuals aged 11-17 or 45-54 years, getting off the escalator, and the emergency stop not being pressed. Together these factors could suggest locomotor adaptation issues when disembarking from the moving escalator to the stationary landing surface, leading to the emergency stop being activated. Current research in this area is limited to the embarkation of moving surfaces (Hsu et al. 2015) and so future research could focus on the transition from moving to stationary surfaces. In addition, another factor group suggested that injuries involving those aged less than 10 also tended to include unexpected movement (e.g., walking) and the escalator not operating normally (i.e., switched off). This finding is likely due to the fact that the step height on an escalator is 24cm, which is greater than the 17.8cm height deemed safe for stair locomotion (Jacobs, 2016). Therefore, an intervention could focus on discouraging escalator users (in particular younger children) from using switched off escalators as staircases, as they are not designed for such purpose (BS EN 115-1:2017: British Standards Institute, 2017). Alternatively, a mechanical redesign of an escalator to make them more user-friendly for walking could be considered.

In summary, the design of the HFIT-MP allows a user to identify those performance influencing factors (PIF) which occur when a member of the public has an escalator incident. Whilst, solely using the frequency count of PIFs may tell the user what are the most numerous, value is added by using MCA to explore the relationships between PIFs providing a health and safety practitioner with a more informed analysis of where interventions may be targeted.

5.3 FUTURE DIRECTIONS

Although the focus of this study is escalator incidents, it is possible that the HFIT-MP could be applied to other environments where members of the public are at risk of injury. For example, previous research has highlighted incidents involving members of the public when using stairways (Jacobs, 2016), when on amusement park rides (Woodcock, 2008), when using a swimming pool (Peden & Franklin, 2020) or playground equipment (Keays & Skinner, 2012). Future research could therefore seek to expand and evaluate the use of the HFIT-MP to other environments beyond escalators.

The data analysed in the current study consisted of serious escalator incidents reported to the HSE where the injured individual required hospital treatment. As there is no other central repository for escalator incidents within GB, the HSE database and this analysis provides invaluable understanding of a range of incidents that occurred across multiple organisations and geographical locations. Furthermore, it is pertinent to acknowledge that less serious escalator incidents can occur (DeMers et al., 2011) and the factors that contribute to these incidents may not be equivalent to the incidents identified in the current study. Given that accidents that don’t require hospital treatment are likely to take place and be recorded by respective organisations through their own internal health and safety reporting procedures, future work could aim to examine a wider sample of escalator incidents to build a better understanding of the multi-faceted nature of such accidents (Howland et al., 2012). Furthermore, examination of a wider sample of incidents would enable a further level of rigour to be applied to the HFIT-MP developed in the current study.

In addition to using other data sources, it would be prudent to examine escalator incidents using data collected through other means than narrative incident reports. For example, an observational approach will provide more objective data, reducing potential bias and/or inconsistencies in narrative reports (Malterud, 2001; Rossignol, 2015). By way of example, Robinovitch et al. (2013) recorded and coded closed-circuit television (CCTV) footage of fall incidents in care home settings as a method to observe and systematically quantify the causes of falls in older adults. Such methodology could be applied to escalator incidents to provide further understanding on the reasons why escalator incidents may happen and to help shed light on some of the 'unknown' factors that were named in some of the RIDDOR incident reports examined in the current study. With such suggestion in mind, the HFIT-MP developed in the current study provides a framework for the systematic coding of video data to examine the Human Factors associated with escalator incidents. Further, considerations should also be given to qualitative methods such as in-depth interviews with at-risk populations (Hanson, Balmer, & Giardino, 2011) to provide further insight as to why someone over the age of 65 may be at particular risk of a fall on an escalator. For example, Yardley et al. (2006) used a qualitative method to understand older persons' perceptions of fall prevention advice, offering valuable insights that any such advice needs to be relevant, and deemed applicable to an older person to be effective.

5.4 CONCLUSION

Escalator incidents are seldom the result of one causal factor, rather a cumulation of PIFs. In order to examine the multi-faceted nature of escalator incidents, the present research developed a new taxonomy - the Human Factors Incident Taxonomy for Members of the Public (HFIT-MP) - using a combination of academic literature, subject matter expertise and two existing HF taxonomies. The applicability of this taxonomy was assessed by applying it to the HSE dataset of GB escalator incidents and was found to have reasonable inter-rater reliability. Subsequent analysis revealed potential combinations of factors that are frequently reported together when an escalator incident occurs. For example, fall incidents frequently occurred with persons over the age of 65, traveling alone, losing footing, getting onto the escalator, and the escalator descending. This analysis provides researchers and health and safety practitioners alike, with new understanding on the pertinent factors that may contribute to escalator incidents, which can be utilised in the development of interventions. This research also highlights the need to improve narrative reporting of incidents as indicated by the high proportion of missing information for identified PIFs. Future work would benefit from using the HFIT-MP on different escalator injury datasets, observational research using footage of incidents, and qualitative techniques to further enhance understanding on the factors contributing to escalator incidents.

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7 DECLARATION OF INTEREST

The lead author is an employee of the Health and Safety Executive and a postgraduate student at the University of Portsmouth.

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9 APPENDIX

9.1 APPENDIX A

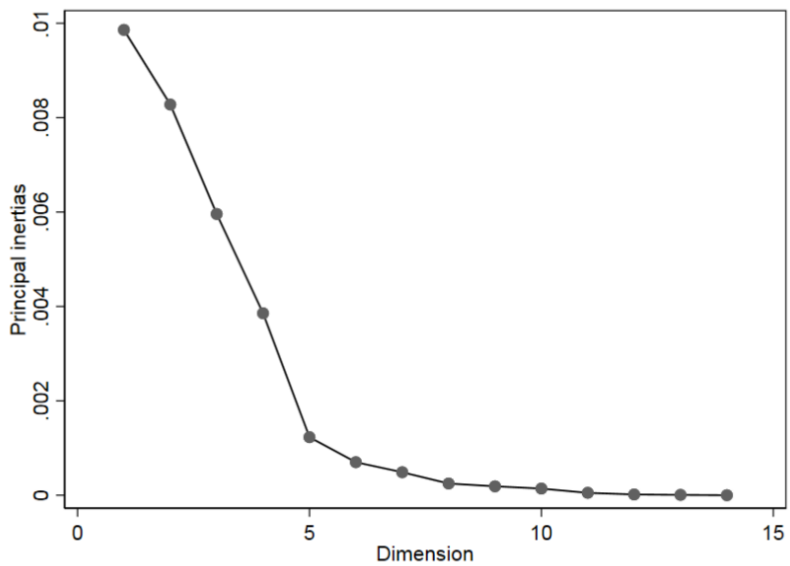

Figure 5 Scree plot of principal inertias after Multiple Correspondence Analysis

9.2 APPENDIX B

Table 6 Duda-Hart Index for each cluster solution*

Number of clusters	Je(2)/Je(1) index	Pseudo T-squared
2	0.6542	15.33
3	0.5449	7.52
4	0.6388	13.01
5	0.3742	10.03
6	0.4047	5.88
7	0.0305	31.83
8	0.6660	7.02
9	0.1337	12.96
10	0.6147	4.39
11	0.4957	12.21
12	0.0000	NE
13	0.3948	4.60
14	0.5972	4.05
15	0.4586	10.63
16	0.5094	4.82
17	0.0419	22.89
18	0.1051	8.51
19	0.5064	1.95
20	0.0675	13.82

NE, not estimable

* Larger values of the Je(2)/Je(1) index and smaller values of the Pseudo T-squared values indicate more distinct clustering

9.3 APPENDIX C

Table 16 Groupings of value labels based on Multiple Correspondence Analysis followed by cluster analysis. Ordered by indicator of strength of association (strongest first).

Category ID	Factor: Category	Strength of association within group [1]
Group 7		4
11	**Individual**: Aged 25 – 34	
41	**Outcome**: Entrapment	
Group 8		3
9	**Individual**: Aged 11 – 17	
13	**Individual**: Aged 45 – 54	
20	**Task**: Getting off the escalator	
34	**Outcome**: Emergency stop not pressed	
Group 3		2
14	**Individual:** Aged 55 – 64	
42	**Outcome:** Unclear incident	
36	**Task:** Unknown if getting on, off or already 'on; escalator	
32	**Task:** Unknown if unexpected movement on the escalator	
3	**Environment:** Escalator direction unknown	
Group 5		2
7	**Individual:** Aged 0 – 5	
8	**Individual:** Aged 6- 10	
30	**Task:** Unexpected movement on the escalator	
5	**Environment:** Escalator not operating normally	
Group 1		1
12	**Individual:** Aged 35 – 44	
26	**Task:** Lost balance	
35	**Task:** Already 'on' the escalator	
37	**Task:** Traveling with companions	
24	**Task:** Collision with another user	
1	**Environment:** Ascending escalator	
4	**Environment:** Escalator in normal operation	
19	**Outcome:** Emergency stop button pressed	
29	**Task:** Unknown if lost footing	
Group 2		1
15	**Individual:** Aged 65 – 74	
16	**Individual:** Aged 75 – 84	
17	**Individual:** Aged 85 +	
33	**Task:** Getting on the escalator	
28	**Task:** Lost footing	
31	**Task:** No unexpected movement on the escalator	
38	**Task:** Not traveling with companions	
2	**Environment:** Descending escalator	
40	Outcome: Fall	
18	**Individual:** Age unknown	
27	**Task:** Unknown if lost balance	
39	**Task:** Unknown if traveling with companions	
25	**Task:** Unknown if collision with another user	
23	**Task:** Unknown if clothing was caught	

6	**Environment:** Unknown if escalator operating normally	
21	**Outcome:** Unknown if emergency stop was pressed	
Group 4 - outlier		**N/A**
10	**Individual:** Aged 18 – 24	
Group 8 – outlier		**N/A**
12	**Task:** Item of clothing caught	

[1], based on Euclidean distance of group centroid from origin:
4 strongest association; 1 weakest association.