Gestures: The Reformer of the User's Mental Model in Mobile HCI

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Abstract. This paper, by making a usability testing of four Chinese mainstream apps, finds that the mental model's spatial consistency can directly affect the mobile performance. Meanwhile, it also finds that in the touch-screen environment, the concept of direction is ignored by the app users when they construct mental models. Further experimental studies show that:1) mental model's spatial consistency and Gestalt can influence the gesture's direction, and the Gestalt's impact on it is stronger than that of mental models; 2) in performance the subjects have ignored the time's growth caused by the misdirected gestures, and the completion time is no longer an evaluation criteria for the satisfaction; 3) information type significantly affects completion time, and the hints produced by the continuity of the information content do not influence the direction of gesture ; 4) the difference of interaction devices is actually the reason that a user notices the direction or not.

Keywords: spatial consistency, direction of gesture, user experience, mobile usability.

1 Introduction

Since the year of 2008 the app emerged, it has become an indispensable tool for our work, living, recreation, getting information, consumption, communications and social network. The app has changed our lifestyle.

Although we can download thousands of apps, we do not get the same amount of high quality user experience as that of apps. Many apps have problems in usability and user experience, although their development follows their own platform's design and development guidelines.

This article, based on the interface consistency, tries to explore the relationships between gestures and mental models, which can be taken as a way to improve the app's user experience.

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2 Literature Review

Interface consistency is a notion widely accepted by academia and industry in the field of interactive design. It can make a user to transfer his existing knowledge naturally into a new application environment, and then apply it to learn and predict the novel environment more quickly. Moreover, the consistency can also make a user to feel a sense of familiarity and reliability. That is why the interface consistency has been as a kind of fundamental design guidelines to enhance the user experience, and has been almost in all the major operating systems and software since the 1990s. For example, in the guidelines of Windows 95, "consistency is important through all aspects of the interface, including names of, consistency, forgiveness, feedback, aesthetics, and simplicity"; in the MAC commands, visual presentation of information, and operational behavior"; in the Eclipse's User Interface Guidelines, "the basic UI design principles are user in control, directness OS X's The Philosophy of UI Design, "consistency in the interface allows users to transfer their knowledge and skills from one app to another. Use the standard elements of the Aqua interface to ensure consistency within your app and to benefit from consistency across apps."

Scholars' research on the interface consistency has begun in the 1970s. So far, never stopped. Most studies have concentrated on the three concerns, namely the operation time, the error rate and the satisfaction. For instance, Schneider et al. successively through experimental research concluded that a system with a consistent interface could reduce the task's completion time and the error rate, and meanwhile increase users' satisfaction [1],[2].Egbert by GOMS method found that when the concept of consistency was introduced into the interface design, the performance time of users was significantly shortened[3]. Unfortunately, although scholars have done so much research on the interface consistency, so far, a unified, recognized definition of interface consistency has not formed. Literature records that in 1989 in a two-day workshop 15 experts discussed the interface consistency and tried to define it, but ultimately they did not form a universally accepted definition of it[4].

In the study of the interface consistency's content domain, Grudin divided the consistency into three categories which were the internal consistency, the external consistency and the metaphoric consistency[5]. Internal consistency referred that in a program the physical properties of interface elements, etc., should maintain consistency or similarity. External consistency referred that the interface features of a program should be consistent with other program interface's features. Metaphoric consistency was that the icons' shape and meanings on the interface should be consistent with the one in the real world. Tanaka et al. [6] classified the interface consistency as the cognitive consistency and the display consistency. The former referred that the semantics of the interface elements was consistent with a user's understanding to the elements. The latter referred to the consistency of the visual information such as interface layout. Adamson and Wallace divided the interface consistency into three levels which were the conceptual level, the communicational level and the physical level[7]. The conceptual level was the consistency of metaphor applied to interface elements and interactive behaviors, such as languages, overall task concept and skill transfer; the communicational level referred to the consistency of the input and the output, such as moving between screens; the physical level was that of the graphical appearance, like symbols, size, shape, and color. Mandel, T. thought that the interface consistency included three types which were consistency in presentation, consistency in behavior and consistency in interaction techniques[8] . No matter how divided, there are three types of interface consistency mentioned by the most research, that is, the visual consistency (such as layout, fonts and colors), the metaphorical and semantic consistency and interactive behavior consistency.

The role of interface consistency to enhance the program's user experience and usability is obvious to all, but other studies have shown that it lets interface design lost the ability of innovation, hinders the development of new interactive technologies, and also makes designers to deviate from the user-centered design philosophy and lets the programs produce some usability issues[9]. Microsoft in the UI Guidelines vs. Usability Testing wrote that "consistency by itself is not the ultimate goal. Moreover, consistency in itself doesn't ensure usability. It is a mistake to think that consistency in the surface properties of the interface will lead to good design"。It implies that there is a thing existing between interface consistency and usability, which determines whether it is a positive correlation between them or not. It is the mental model. Many studies have manifested that the mental model plays a very important role in HCI.

The emergence of smart devices changes the world greatly. Mobile living, mobile working and mobile recreation are everywhere. Naturally, the app becomes the effective tool for enriching this kind of lifestyle. Considering the interface consistency's admirable effects in improving user experience for the PC users, it has been brought into the mobile internet industry to enhance the mobile user experience. For example, consistency in IOS 7 is considered as a design strategy which lets people transfer their knowledge and skills from one part of an app's UI to another and from one app to another app. An app running in IOS7 should have three levels of consistency that :1) it is consistent with the IOS 7 standards, 2) it is consistent with itself, and 3)within reason, the app is consistent with its earlier versions. It is noteworthy that gestures in IOS7 are suggested as shortcuts to expedite a task. Similar to IOS 7, Android and Windows phone provide different design guidelines for app developers to enhance the interface consistency and user experience. In them Android clearly states that if it looks the same it should act the same, while Windows phone takes the motion as a new element of improving interface consistency.

However, either a computer user or a mobile device user, his operation is mostly based on a task or a purpose. It means that a user would integrate all the stuffs appearing in the process of the task, such as different interfaces and gestures, and form a spacial mental model about completing this kind of task, and then use it to accomplish similar tasks. Some studies have found that the spatiality of mental model played a very important role in properly using the mobile device and improving the search performance of the layered information[10],[11],[12], and in the mobile phone based on Symbian OS the interface based on lattic-lattic mental model with a good spatial consistency had a higher interaction performance than the lattic-column mental model which had a bad spatial affordance[13].However, in the existing design guidelines, consistency is defined basically from the two levels which are the interface level and the gesture level. There is no design guidelines about the spatial consistency occurring in the whole interactive process. For example, in some apps, the event of viewing information at the same level is designed to the pattern of the horizontal fixed tab plus horizontal swipe at the first level page, and the one of the vertical list plus vertical swipe at the second page, and the one of the lateral text plus horizontal sliding according to the current design guidelines. That is, the event of viewing the same level message in these apps is set to three design patterns. Obviously, it not only brings the confusions to the user’s mental logic, but also increases the user's mental workload. Moreover, it is likely to affect or reduce the user's mobile experience.

Based on the gestures, this paper will explore the influence of the mental model’s spatial consistency on the apps’ user experience and usability, and explain the reasons by several quantitative experiments.

3 Usability Testing of the Popular Chinese Apps

The purpose of this test is to explore whether the mental model’s spatial consistency mapped out by the app can affect its usability and user experience.

Four currently popular Chinese apps were selected, which were 360 mobile assistant, Baidu news, Douban film and Moji Weather. Six experts with rich experience in interactive design and interface design were invited to mark the four apps’ spatial consistency with a 5–point scale. And then fifteen college students with the ages of 18-25 years old were selected. Eight dependent variables were chosen according to the PACMAD mobile usability model[13]. Experimental tasks were to find out a targeted headline and read its content in each app.

Table 1. Results of the ANOVA

		Sum of Squares	Mean Square	F	Sig.
Effectiveness	Between Groups	14.143	1.088	1.478	.162
	Within Groups	33.857	.736		
Efficiency	Between Groups	25.957	1.997	1.694	.095
	Within Groups	54.226	1.179		
Satisfaction	Between Groups	24.067	1.851	2.094	.033
	Within Groups	40.667	.884		
Learnability	Between Groups	15.874	1.221	2.272	.021
	Within Groups	24.726	.538		
Memorability	Between Groups	12.457	.958	1.317	.238
	Within Groups	33.476	.728		
Effect on walking	Between Groups	12.731	.979	.991	.475
	Within Groups	45.452	.988		

Results show that:

1. The mental model’s spatial consistency have significant impacts on the learnability and user satisfaction, shown in Table 1, and their probability values of the significance test are 0.021 and 0.033 respectively, both less than 0.05. It indicates that the spatial consistency of mental model has affected users indeed.

2. There is a positive correlation between the spatial consistency and each of the efficiency, learnability and satisfaction. The correlation coefficients are 0.468, 0.717 and 0.636 respectively, as showed in Table 2. They all have the significance at the 0.01 level. It means that the higher the spatial consistency of a mental model is, the more the user can feel satisfied.
3. The approval rate of "the same event with the same gesture" is up to 80%, but the approval rate of "the same event operated by a gesture with one direction only" is less than a half, up to 48.3%. This seemingly paradoxical approval conveys an important message that the concept of direction may have been weakened by the users in the process of building a mental model in apps. It is very different that the direction is an important factor in building a mental model of a physical interaction.

Table 2. Results of the correlation analysis

		Efficiency	Satisfaction	Learnability	Mental model score
Efficiency	P. Correlation	1	.239	.277*	.468**
	Sig. (2-tailed)		.066	.032	.000
Satisfaction	P. Correlation	.239	1	.703**	.717**
	Sig. (2-tailed)	.066		.000	.000
Learnability	P. Correlation	.277*	.703**	1	.636**
	Sig. (2-tailed)	.032	.000		.000
Mental	P. Correlation	.468**	.717**	.636**	1
Model score	Sig. (2-tailed)	.000	.000	.000	

There are three possibilities that lead to the users' shift, as follows:

1. It is related to the fact that gestures have become a shortcut in the touchscreen environment. The screen is small, the information is less, and the gestures are fast. So even if a user uses a gesture in the wrong direction he will immediately try out the right direction. Speed overcomes everything.
2. Each information has its specific content and form, and the continuity of the information content will generate a hint about the direction. To get more contents, a user will take advantage of this hint and make a corresponding gesture. If the user is highly accustomed to the direction produced by the information content, then he will ignore the semantic hint when constructing the mental model.
3. Compared with the mouse interaction, the gesture is more natural and more easily summarized into unconscious behavior. Therefore, it is more likely to be ignored.

Response to these three possibilities, we made further experiments.

4 Experiment Ⅰ -Task Time and the Gesture Direction

Experiment 1 is the designed for the first possibility, and its purpose is to study the relationship between the task's completion time and the gesture direction.

The experiment's independent variables were the page layout and the Gestalt. The former could affect the formation of a user's mental model, and it had two variable levels which were "the horizontal layout at the first page – the horizontal layout at the second page" and "the horizontal layout at the first page – the vertical layout at the second page". The latter could influence a user's cognition and understanding of graphs, and it also had two variable levels, namely the strong and the weak.

In these four factors cells, a half ones mapped out the mental models with the spatial consistency (Sample B, D), and the other half mapped out the inconsistent ones(Sample A, C). The dependent variables were the time to complete the task, the subjects' perceived degree of the Gestalt, the error count and the user satisfaction. Experimental material was shown in Fig.1. The subjects were the same as the previous usability testing. Experimental task was to find a targeted color bar and click it.

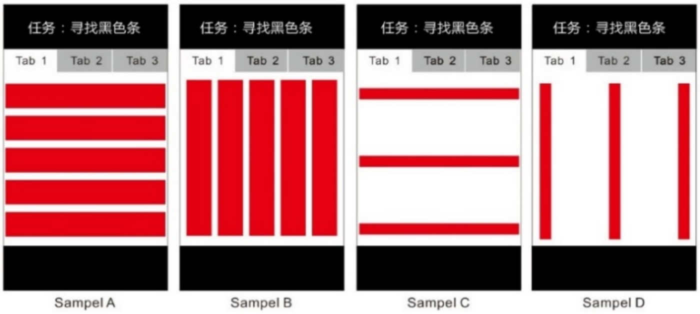

Fig. 1. The materials of experiment 1

Table 3. Results of the UNIANOVA

Source	Type III Sum of Squares	Mean Square	F	Sig.
Corrected Model	7.023E8	2.341E8	6.849	.001
Intercept	7.839E9	7.839E9	229.331	.000
Degree of Mental Model Consistency	2.343E8	2.343E8	6.853	.013
Degree of Gestalt	4.333E8	4.333E8	12.677	.001
Degree of Mental Model Consistency * Degree of Gestalt	34744422.914	34744422.914	1.016	.321
Error	1.094E9	34182689.056		
Total	9.635E9			
Corrected Total	1.796E9			

Experimental results show that:

1. The page layout and the Gestalt have significantly affected the subjects' time to complete the task. The corresponding probability values of the significance test are 0.013 and 0.001 respectively, both less than 0.05. There are no interaction effects between the two independent variables because the probability value of the significance test was 0.321, more than 0.05, as shown in Table 3.This means that

the spatial consistency of mental model mapped out by the page layout and Gestalt, the organizing principles of graphs in cognitive space, both affect the subjects' completion time, but do not influence each other.

2. The marginal mean of completion time with the spatial consistency and the strong Gestalt (Sample B) is the minimum, 9718.5 milliseconds, and the one without the spatial consistency and with the weak Gestalt (Sample C) is maximum, 21,759 milliseconds, seen in Fig. 2. Combined Table 3, we can conclude that the impact of Gestalt on the completion time is stronger than that of mental models.

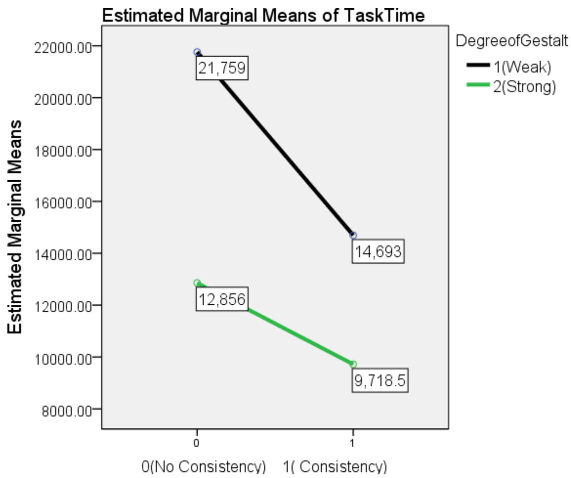

Fig. 2. Profile plots of the interaction effect between page layout and Gestalt

3. There is a negative correlation between the subjects' completion time and their perceived level of Gestalt. The correlation coefficient r is -0.442, which is statistically significant, seen in Table 4. It implies that the more the subjects feel the directional hint caused by the proximity and isotonicity of Gestalt, the faster they operate. Note that the user's selection of gesture direction is also influenced by the mental model's spatial consistency, yet its intensity of impact is less than that of Gestalt.

Table 4. Results of the correlation analysis

		Perceived Level of Gestalt	Task Time
Perceived Level of Gestalt	Pearson Correlation	1	-.442**
	Sig. (2-tailed)		.007
Task Time	Pearson Correlation	-.442**	1
	Sig. (2-tailed)	.007	

4. There is no correlation between the subjects' completion time and the error count. And there is likewise no correlation between the time and the user satisfaction. But, there is a negative correlation between the error count and the user satisfaction, whose correlation coefficient r is -0.413, as shown in Table 5. It manifests that in the aspect of performance the subjects have ignored the time's

growth caused by the misdirected gesture. The completion time is no longer one of the evaluation criteria for the user satisfaction, but the error count has an effect on the user satisfaction indeed.

5 Experiment Ⅱ-Information Type and Gesture Direction

ExperimentⅡis designed for the second possibility that the user ignored the gesture direction in using apps. Its aim is to explore the relationship between the hints produced by the information's form and the user's selection of the gesture direction.

Table 5. Results of the correlation analysis

		Task Time	Error	Satisfaction
Task Time	Pearson Correlation	1	-.040	-.286
	Sig. (2-tailed)		.819	.090
Error	Pearson Correlation	-.040	1	-.413*
	Sig. (2-tailed)	.819		.012
Satisfaction	Pearson Correlation	-.286	-.413*	1
	Sig. (2-tailed)	.090	.012	

In this experiment, the factor Gestalt was controlled because it could cause the gestures' direction of motion. The independent variables were the page layout and the type of information. According to the richness, the type of information was divided into three levels: text, picture and flash animation. The page layout was the same as the experiment 1. In the six factors cells, a half ones mapped out the mental models with the spatial consistence, and the other half mapped out the inconsistent ones. The dependent variables were the completion time, the subjects' perceived level of semantic hint and the error count. Experimental material was presented in Fig.3. The subjects were the same as the experiment 1. The task was to identify a targeted information bar and click it.

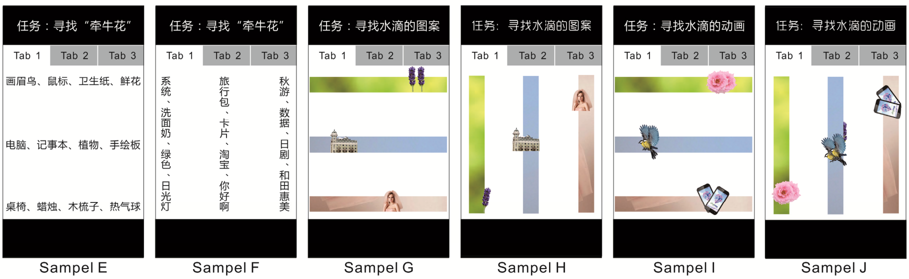

Fig. 3. The materials of experiment Ⅱ

The results show that:

1. The significance test's probability values of the main effects of the information type and the mental model to the completion time are both less than 0.05, seen in

Table 6. It means that both of them have significant influences on the subjects' completion time. The time subjects spent in the experimental material with the spatial consistency is less than that of the inconsistent mental model. And the time spent in the text material is minimum, and that expended in the flash animation is maximum, seen in Fig.4.

Table 6. Results of the UNIANOVA

Source	Type III Sum of Squares	Mean Square	F	Sig.
Corrected Model	4.810E9	9.620E8	10.030	.000
Intercept	4.147E10	4.147E10	432.333	.000
Info Type	3.892E9	1.946E9	20.287	.000
Degree of Mental Model Consistency	5.166E8	5.166E8	5.386	.022
Info Type* Degree of Mental Model Consistency	4.017E8	2.009E8	2.094	.129
Error	9.208E9	95913595.717		
Total	5.548E10			
Corrected Total	1.402E10			

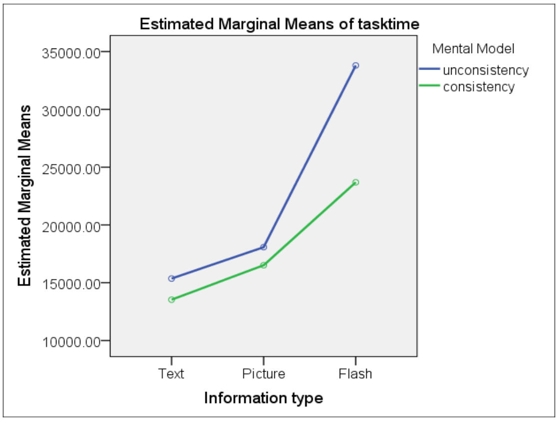

Fig. 4. Profile plots of the interaction effect between page layout and information type

2. There is no interaction effect between information types and mental models, and the corresponding probability value of the significance test is 0.129, greater than 0.05. It indicates that there is no relationship between the semantics of the direction released from the information content and the mental model's spatial consistency mapped out from the experimental materials. They have no impact on each other.
3. The correlation coefficient between the subjects' perceived hints produced by the continuity of information content and completion time is -0.109, seen in Table 7. It is very weak and not significant. This indicates that the hints caused little attention to the users and do not let them make a gesture response, too.
4. There was a negative correlation between the subjects' completion time and the error count. Their correlation coefficient r was -0.257 which was statistically

significant, as shown in Table 7 . It means that the error count has an effect on the user's completion time when the information content gets complex. It is distinct from the result of Experiment 1.

Table 7. Results of the correlation analysis

		Perception of Semantics	Error	Task Time
Perception of	Pearson Correlation	1	-.257**	-.109
Semantics	Sig. (2-tailed)		.009	.277
Error	Pearson Correlation	-.257**	1	-.040
	Sig. (2-tailed)	.009		.686
Task Time	Pearson Correlation	-.109	-.040	1
	Sig. (2-tailed)	.277	.686	

6 Experiment Ⅲ -Interactive Device and Direction

This experiment was conducted for the third possibility that the user overlooked the direction of gesture. The aim was to study the impact of interactive devices' changing on the users' mental model. Experimental variables, tasks and subjects were the same as experiment Ⅱ.Besides these, a new dependent variable was added into this experiment, which was the subjects' perceived level of the direction of the behavior. In the experiment, subjects were requested to complete all the tasks on a PC, and then after a short break they did them again on a smart phone.

Experimental results are as follows:

1. By using the analysis of repeated measures of variance, there is a significant difference in completion time in the two interactive modes. The F-test's probability values by applying the four methods are all less than 0.05, as shown in Table 8.

Table 8. Results of the tests of within-subjects Effects

Source		Type III Sum of Squares	Mean Square	F	Sig.
Task Time	Sphericity Assumed	2.863E9	2.863E9	38.080	.000
	Greenhouse-Geisser	2.863E9	2.863E9	38.080	.000
	Huynh-Feldt	2.863E9	2.863E9	38.080	.000
	Lower-bound	2.863E9	2.863E9	38.080	.000
Error(Task Time)	Sphericity Assumed	7.592E9	75170438.127		
	Greenhouse-Geisser	7.592E9	75170438.127		
	Huynh-Feldt	7.592E9	75170438.127		
	Lower-bound	7.592E9	75170438.127		

2. The two interactive modes have significant effects on the subjects' completion time. The F-test's probability values by applying the four methods are all less than 0.05, as shown in Table 9.

Table 9. Results of the multivariate tests

Effect		Value	F	Hypothesis df	Error df	Sig.
Task Time	Pillai's Trace	.274	38.080[a]	1.000	101.000	.000
	Wilks' Lambda	.726	38.080[a]	1.000	101.000	.000
	Hotelling's Trace	.377	38.080[a]	1.000	101.000	.000
	Roy's Largest Root	.377	38.080[a]	1.000	101.000	.000

3. On the PC side, there is a significant negative correlation between the completion time and the subjects' perceived level of the direction of the behavior. The correlation coefficient r is -0.648 (Table 10). But on the mobile side, the correlation coefficient is -0.078(Table 11). This means that on the PC side the direction is an important factor to construct a mental model while on the mobile side it is ignored by the users. It is related to the mouse interacion's larger moving path and time-consuming operation and the gesture interaction's less moving path and rapid speed.

Table 10. Results of the correlation analysis

		PC Task Time	PC Perception of Direction
PC Task Time	Pearson Correlation	1	-.648**
	Sig. (2-tailed)		.000
PC Perception of Direction	Pearson Correlation	-.648**	1
	Sig. (2-tailed)	.000	

Table 11. Results of the correlation analysis

		SP Task Time	SP Perception of Direction
SP Task Time	Pearson Correlation	1	-.078
	Sig. (2-tailed)		.436
SP Perception of Direction	Pearson Correlation	-.078	1
	Sig. (2-tailed)	.436	

7 Summary

This paper, by making a usability testing of the four mainstream Chinese apps, finds that the mental model's spatial consistency is one of the reasons that produces a difference in the mobile interaction performance. Meanwhile, it also finds that in the touch-screen environment, the concept of direction which is very important in a real physical interaction is ignored by the app users when they construct the mental models. Further experimental studies show that:

1. mental model's spatial consistency and Gestalt can have effects on the gesture's direction, and the force of Gestalt on it is stronger than that of mental models.

2. in the aspect of mobile performance the subjects have ignored the time's growth caused by the misdirected gestures. The completion time is no longer the evaluation criteria for the user satisfaction.
3. the information type significantly affects the subjects' completion time, and the hints produced by the continuity of the information content do not affect the gesture's direction.
4. the difference of interaction devices is actually the reason that a user notices the direction.

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